THE GEOLOGICAL CONCEPT OF MOUNTAINS IN THE QUR'AN

Z. R. EL-NAGGAR

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AL-FALAH FOUNDATION
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CONTENTS

Preface

﴿*We will show them Our Signs in the universe, and in their ownselves, until it becomes manifest to them that this (the Qur'an) is the truth. Is it not sufficient in regard to your Lord that He is a Witness over all things?*﴾

(Fussilat: 53)

Indeed, the Glorious Qur'an remains the ever-lasting miracle that witnesses to the truthfulness of Muhammad's Message. Whenever you approach its Divine Words, you find a wonder that will snatch both your heart and mind at the same time. Moreover, the miraculous nature of the Glorious Qur'an is not confined to a certain field or time but it emerges to challenge people in whatever field they master. That is why we can touch different faces to its miraculous nature; its style, its sciences and its impact upon mankind that changes the face of history or all such matters together.

To all seekers of truth I pray them to consider the Glorious Qur'an whose miracles address people at all times and to consider the Messenger to whom it was revealed or to imagine another genius person equipped with the talent of an artist, the power of a leader and all the studies of humanities and then let me ask them: Have you found but a power that transcends any other power, and surpasses the potentialities of any scientist, leader or poet? So, generation after generation and age after age, the miraculous nature of the Glorious Qur'an is always here.

It is Allah's Book that came to defy the Arabs, the masters of eloquence at that time, by its outstanding rhetorical nature. And now, when mankind attains a high degree of knowledge, we come to uncover in the Glorious Qur'an signs to scientific facts discovered in the modern age. This is nothing but a great witness to the Divine nature of this Book and a proof of its truthfulness.

Al-Falah Foundation has the great honor to introduce to its dear reader the first fruits of this series about the miraculous nature of the Glorious Qur'an. Also, we would like to express our deep thanks to Dr. El-Naggar for his efforts in such a field, supplicating Allah, the Almighty, to make it of profit to Islam and Muslims. Praise be to Allah through Whose bless the good deeds are completed.

General Director

Sheikh Muhammad `Abdu

INTRODUCTION

Literally, the word "mountain" (Latin *Montanus*) is described as "a landmass that projects conspicuously above its surroundings and is higher than a hill[1]."

The Dictionary of Geological Terms[2] (1976, p. 289) defines a mount or a mountain as a high hill (but mount is always used instead of mountain before a proper name). A mountain is also defined (loc. cit.) as a tract of land considerably elevated above the adjacent country, and is usually found connected in long chains or ranges, but sometimes can be in the form of single, isolated eminences. From the point of view of physical geography, the same dictionary (op. cit.) adds that any portion of the Earth's crust rising considerably above the surrounding surface is described as a mountain. The term is usually applied to heights of more than 610 meters, all beneath that amount being regarded as hills, and when of considerable heights, hillocks. Nevertheless, in the same issue (p. 207), a hill is defined as "properly restricted to more or less abrupt elevations of less than 305 meters, all altitudes exceeding this being mountains." Indeed, in many of the American references, elevations above 300 meters are considered mountains.

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1. *Webster's Seventh New Collegiate Dictionary* (1971), B. & C. Merriam Co., Publisher; Springfield, Massachusetts, U.S.A.
2. *Dictionary of Geological Terms* (1976), Revised edition prepared under the direction of the American Geological Institute; Anchor Books Edition, U.S.A.

A mountain range is defined (op. cit.) as a single, large mass consisting of a succession of mountains or narrowly spaced mountain ridges, with or without peaks, closely related in position, direction, formation and age. A mountain range is a component part of a mountain system or a mountain chain. The former is defined as "several more or less parallel ranges grouped together," while the latter is described as "a complex, connected series of several, more or less parallel mountain ranges and mountain systems grouped together without regard to similarity of form, structure or origin, but having "a general longitudinal arrangement or well-defined trend ..."

In other words, a mountain range is a series of more or less parallel ridges, all formed from rocks deposited in a single sedimentation basin, while a mountain system is composed of a number of parallel or consecutive ranges, formed from the sediments of different basins, but of approximately the same age of folding.

A mountain chain consists of two or more mountain systems of the same general trend and elevation, while a cordillera is formed of several chains in the same part of a continent (cf. Milligan, 1977, p. 445).

In "*the Dictionary of the Natural Environment*," Monkhouse & Small (1978) define the term "mountain" as follows: "A markedly elevated landform, bounded by steep slopes and rising to prominent ridges or individual summit-peaks. There is no specific altitude, but usually taken to be over 600 meters (2000 ft.) in Britain, except where eminences rise abruptly from surrounding lowlands, e.g. Conway M. In such a case, the term Mount is sometimes used ..."

The New Encyclopedia Britannica defines a mountain as "an area of land that is relatively much higher than the land surrounding it" and adds "thus, the so-called hills associated with great ranges such as the Himalayas would be mountains in a less formidable setting."

Similarly, *the Encyclopedia Americana* defines a mountain as a portion of the Earth's surface that rises above the surrounding region" and add, "Generally, a mountain range decreases in height in stages, with a transition through hills to lower regions called plains. However, in some cases the transition is extremely rapid. Mountains occur worldwide, in both continental and oceanic regions."

From the above survey, it becomes obvious that all current definitions of mountains, both literal and scientific, restrict themselves to the conspicuous protrusion of such landforms above their surroundings, their high peaks and steep sides, as well as to their presence in either complex ranges, systems, chains, and cordilleras that run more or less parallel to each other or in single prominences. In other words, all current definitions of mountains are only confined to the outer morphology of such landforms, without the slightest notion to their subsurface extensions which have been lately proved to be several times their outward heights.

However, the Qur'an consistently describes mountains as stabilizers for the Earth's surface which hold it firmly lest it should shake with us, and as pickets (or pegs) for the Earth that hold its surface (i.e. the Earth's lithosphere) down as a means of fixation. So, the Qur'an - in very simple words - described the outward protrusion of mountains on the Earth's surface,

emphasized their great downward extensions within the Earth's crust, and defined their exact role as pickets and means of fixation for that crust. Such knowledge was revealed more than 12 centuries before man started to wonder whether or not mountains could have roots below its outcropping parts, and before he could realize any value for the existence of mountains on the surface of our globe, a value that is only being currently conceived by a very limited number of specialists in the field of Earth Sciences.

THE REFERENCE TO MOUNTAINS IN THE QUR'AN

Frequency of Verses

The word mountain in both the singular and plural forms is explicitly mentioned in the Qur'an 39 times (6 in the singular and 33 in the plural), and is clearly implied as stabilizers for the Earth's crust in 10 other verses. These 49 Qur'anic references can be classified in 9 distinctive categories as follows:

1. Verses that refer to a highly elevated landform (2:260 and 11:43)[1].
2. Verses that metaphorically emphasize the greatness of the mountain mass, of its elevation or of its massive, solid nature (13:31; 14:46; 17:37; 19:90; 33:72 and 59:21).
3. Verses that only mention the word mountain (or mountains) in the context of a similitude (11:42 and 24:43).
4. Verses that refer to mountains of historic importance such as those where the Thamud people lived (7:74; 15:82 and 26:149).

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1. In each of these paired numbers, the first indicates the number of the Qur'anic chapter (*Surah*), while the second indicates the number of the Qur'anic verses (*Ayah*) in the *Surah*.

5. Verses that refer to mountains which were the scenes of performed miracles such as the mountains of Prophet Ibrahim (Abraham) (PBUH) or those of prophet Musa (Moses) (PBUH) (2:260 and 7:143, 171).

6. Verses that mention some of the uses of mountains by both human beings and animals as shelters (16:68, 81), and as sources for running water (13:3; 16:15; 27:61 and 77:27).

7. Qur'anic verses that clearly describe mountains as pickets (or pegs) that hold the Earth's surface down as a means of fixation (78:7) and others that emphasize their role as stabilizers for the Earth's crust (13:3; 15:19; 16:15; 21:31; 27:61; 31:10; 41:10; 50:7; 77:27 and 79:32) or point to the miraculous system by which mountains are set-up (88:19).

   A fourth category of verses in the same group describes certain physical aspects of mountains such as their composition of rocks of varied colors and origins (35:27), or emphasizes the fact that despite their enormous mass, mountains are not stationary bodies because they follow the movement of the Earth (27:88). Such verses clearly outline the basic geological concept of mountains, and thus are the main concern of this paper.

8. Verses that refer to mountains in their supernatural, spiritualistic and intangible form as true worshippers of their Creator (21:79; 22:18; 34:10 and 38:18).

9. Special Qur'anic verses that describe the fate of mountains on the Day of Judgment and their complete destruction thereon (18:47; 20:105; 52:10; 56:5; 69:14; 70:9; 73:14; 77:10; 78:20; 81:3 and 101:5).

Qur'anic Verses with Basic Geologic Concepts of Mountains

In 12 distinctive verses, the Qur'an (which is principally a book of divine guidance) outlines the basic geologic concepts of mountains as follows:

1. That mountains are not just the lofty elevations seen on the surface of the Earth, but their downward extensions in the Earth's lithosphere (in the form of pegs or pickets) is highly emphasized. In as much as most of the picket (or peg) is hidden in either soil or rock to hold one end of the tent to the ground surface, most of the mountain must be hidden in the Earth's lithosphere. The term "picket" or "peg" is both literally and scientifically more correct than the term "root" which is currently used for mountains. In Chapter 78 (*Surat* an-Naba' or the Great News), verses nos. 6 and 7, the Qur'an reads:

﴿*Have we not made the Earth as a wide expanse, and the mountains as pegs.*﴾

(An-Naba': 6-7)

﴿أَلَمْ نَجْعَلِ الأَرْضَ مِهَاداً (٦) وَالْجِبَالَ أَوْتَاداً (٧)﴾

(النبأ: ٦-٧)

2. In 10 other verses, the Qur'an emphasizes the role of mountains as stabilizers for the Earth's outer surface (or lithosphere). These verses read:

(a) ﴿*And it is He Who spread out the Earth, and set thereon mountains standing firm, and (flowing) rivers: and fruit of every kind He made in pairs, two and two; He draweth the night as a veil over the day. Behold, verily in these things there are signs for those who consider.*﴾

(Ar-Ra`d: 3)

﴿وَهُوَ الَّذِي مَدَّ الأَرْضَ وَجَعَلَ فِيهَا رَوَاسِيَ وَأَنْهَارًا وَمِن كُلِّ الثَّمَرَاتِ جَعَلَ فِيهَا زَوْجَيْنِ اثْنَيْنِ يُغْشِي اللَّيْلَ النَّهَارَ إِنَّ فِي ذَلِكَ لآيَاتٍ لِقَوْمٍ يَتَفَكَّرُونَ. ﴾

(الرعد: ٣)

(b) ﴿*And the Earth we have spread out, set thereon stabilizers (in the form of mountains) and produced therein all kinds of things in due balance.*﴾

(Al-Hijr: 19)

﴿وَالأَرْضَ مَدَدْنَاهَا وَأَلْقَيْنَا فِيهَا رَوَاسِيَ وَأَنبَتنا فِيهَا مِن كُلِّ شَيْءٍ مَّوْزُونٍ. ﴾

(الحجر: ١٩)

(c) ﴿*And He has set up on the Earth mountains standing firm, lest it should shake with you; and rivers and roads; that ye may guide yourselves.*﴾

(An-Nahl:15)

﴿وَأَلْقَى فِي الأَرْضِ رَوَاسِيَ أَن تَمِيدَ بِكُمْ وَأَنْهَارًا وَسُبُلاً لَعَلَّكُمْ تَهْتَدُونَ. ﴾

(النحل: ١٥)

(d) ﴿*And We have set on the Earth mountains standing firm, lest it should shake with them, and We have made therein broad ways (between mountains) for them to pass through; that they may receive guidance.*﴾

(Al-Anbiya': 31)

﴿وَجَعَلْنَا فِي الأَرْضِ رَوَاسِيَ أَنْ تَمِيدَ بِهِمْ وَجَعَلْنَا فِيهَا فِجَاجًا سُبُلاً لَعَلَّهُمْ يَهْتَدُونَ. ﴾

(الأنبياء: ٣١)

(e) ﴿*Or, who has made the Earth a stable abode; made rivers to flow in its midst; set thereon as stabilizers mountains; and made a separating barrier between the two bodies of flowing water. Can there be another god besides Allah? Nay, most of them know not!*﴾

(An-Naml: 61)

﴿أَمَّن جَعَلَ الأَرْضَ قَرَاراً وَجَعَلَ خِلالَهَا أَنْهَاراً وَجَعَلَ لَهَا رَوَاسِيَ وَجَعَلَ بَيْنَ الْبَحْرَيْنِ حَاجِزاً أَءِلَهٌ مَعَ اللَّهِ بَلْ أَكْثَرُهُمْ لا يَعْلَمُونَ.﴾

(النمل: ٦١)

(f) ﴿*He created the heavens without any pillars that ye can see; He set on the Earth mountains standing firm, lest it should shake with you; and He scattered through it beasts of all kinds. We sent down rain from the sky, and produced (plants) of every goodly kind therein, in pairs.*﴾

(Luqman: 10)

﴿خَلَقَ السَّمَاوَاتِ بِغَيْرِ عَمَدٍ تَرَوْنَهَا وَأَلْقَى فِي الأَرْضِ رَوَاسِيَ أَن تَمِيدَ بِكُمْ وَبَثَّ فِيهَا مِن كُلِّ دَابَّةٍ وَأَنزَلْنَا مِنَ السَّمَاءِ مَاءً فَأَنبَتْنَا فِيهَا مِن كُلِّ زَوْجٍ كَرِيمٍ.﴾

(لقمان: ١٠)

(g) ﴿*He established on it (the Earth) stabilizers (mountains standing firm), high above it and bestowed blessings on the Earth, and measured therein all things to give them nourishment in due proportion, in four days, in accordance with (the needs of) those who seek (sustenance).*﴾

(Fussilat: 10)

﴿وَجَعَلَ فِيهَا رَوَاسِيَ مِن فَوْقِهَا وَبَارَكَ فِيهَا وَقَدَّرَ فِيهَا أَقْوَاتَهَا فِي أَرْبَعَةِ أَيَّامٍ سَوَاءً لِّلسَّائِلِينَ.﴾

(فصلت: ١٠)

(h) ﴿*And the Earth We have spread it out, and set thereon stabilizers (mountains standing firm) and produced therein every kind of beautiful growth (in pairs).*﴾

(Qaf: 7)

﴿والأرْضَ مَدَدْنَاهَا وألقَيْنَا فِيهَا رَوَاسِيَ وأنبَتْنَا فِيهَا مِن كُلِّ زَوْجٍ بَهِيجٍ.﴾
(ق: ٧)

(i) ﴿*Have We not made the Earth (as a place) to draw together the living and the dead. And made therein stabilizers (mountains standing firm) lofty (in stature); and provided for you water sweet (and wholesome).*﴾

(Al-Mursalat: 25-27)

﴿ألَمْ نَجْعَلِ الأرْضَ كِفَاتًا(٢٥) أحْيَاءً وأمْوَاتًا(٢٦) وجَعَلْنَا فِيهَا رَوَاسِيَ شَامِخَاتٍ وأسْقَيْنَاكُم مَاءً فُرَاتًا(٢٧)﴾

(المرسلات: ٢٥-٢٧)

(j) ﴿*And the Earth, thereafter, hath He extended it (to a wide expanse). He draweth out therefrom its moisture and its pasture. And by the mountains hath He firmly fixed it (the earth) for use and convenience to you and your cattle.*﴾

(An-Nazi`at: 30-33)

﴿وَالأرْضَ بَعْدَ ذَلِكَ دَحَاهَا(٣٠) أخْرَجَ مِنْهَا مَاءَهَا وَمَرْعَاهَا(٣١) وَالجِبَالَ أرْسَاهَا(٣٢) مَتَاعًا لَكُمْ وَلأنْعَامِكُم(٣٣)﴾

(النازعات: ٣٠-٣٣)

To elaborate on this function of mountains as stabilizers for the Earth, Prophet Muhammad (PBUH) is reported to have said,

"When Allah created the Earth, its surface started to move and shake and then Allah stabilized it by mountains."[1]

3. In the twelfth verse of this group, the Qur'an is asking people to contemplate a number of phenomena in Allah's creation, including how mountains are set up. Such speculation has led to the theory of Isostasy which can explain how mountains are made to stand on the surface of the Earth. The Qur'an reads:

   ﴿*Do they not look at the camels, how they are created. And at the sky, how it is raised high? And at the mountains, how they are set up? And at the Earth, how it is spread out?*﴾
   (Al-Ghashiya: 17-20)

   ﴿ أَفَلاَ يَنظُرُونَ إِلَى الإِبِلِ كَيْفَ خُلِقَتْ(١٧) وإِلَىَ السَّمَاءِ كَيْفَ رُفِعَتْ(١٨) وَإِلَى الجِبَالِ كَيْفَ نُصِبَتْ(١٩) وَإِلَىَ الأَرْضِ كَيْفَ سُطِحَتْ(٢٠) فَذَكِّرْ إِنَّمَا أَنتَ مُذَكِّرٌ(٢١) ﴾

   (الغاشية:١٧-٢١)

4. In another verse (Fatir: 27), the Qur'an describes mountains as being composed of white and red tracts of various shades of colors and of others that are black and intense in hue. This is probably referring to both continental mountains, (which are dominantly granitic in composition, with overwhelming white and red colours of various shades) and oceanic mountains that are dominantly composed of black colored, basic and ultra basic rocks. Each of these mountain types has got its specific rock (chemical and mineralogical) composition, as well as its specific origin.

1. Imam Ahmad, *Musnad*, vol. 3, p. 124.

The Qur'an reads:

﴿*Seest thou not that Allah sends down rain from the sky; with it we then bring out produce of various colors; and from the mountains are tracts white and red, of various shades of color, and black intense in hue. And so amongst men and crawling creatures and cattle, are they of various colors, those truly who fear Allah, among His srvants, are those who have Knowledge: for Allah is exalted in might, oft-forgiving.*﴾

(Fatir: 27-28)

﴿ أَلَمْ تَرَ أَنَّ اللَّهَ أَنزَلَ مِنَ السَّمَاءِ مَاءً فَأَخْرَجْنَا بِهِ ثَمَرَاتٍ مُّخْتَلِفًا أَلْوَانُهَا وَمِنَ الْجِبَالِ جُدَدٌ بِيضٌ وَحُمْرٌ مُّخْتَلِفٌ أَلْوَانُهَا وَغَرَابِيبُ سُودٌ (٢٧) وَمِنَ النَّاسِ وَالدَّوَابِّ وَالْأَنْعَامِ مُخْتَلِفٌ أَلْوَانُهُ كَذَٰلِكَ إِنَّمَا يَخْشَى اللَّهَ مِنْ عِبَادِهِ الْعُلَمَاءُ إِنَّ اللَّهَ عَزِيزٌ غَفُورٌ (٢٨) ﴾

(فاطر: ٢٧-٢٨)

5. In the last verse of this group, the Qur'an emphasizes the fact that mountains are non-stationary bodies that follow the movements of the Earth, as it reads:

﴿*Thou seest the mountains and thinkest them firmly fixed; but they pass away as the clouds pass away ...*﴾

(An-Naml: 88)

﴿ وَتَرَى الْجِبَالَ تَحْسَبُهَا جَامِدَةً وَهِيَ تَمُرُّ مَرَّ السَّحَابِ صُنْعَ اللَّهِ الَّذِي أَتْقَنَ كُلَّ شَيْءٍ إِنَّهُ خَبِيرٌ بِمَا تَفْعَلُونَ. ﴾

(النمل: ٨٨)

MODERN GEOLOGICAL CONCEPT OF MOUNTAINS

A. Deficiency in the Gravitational Attraction of Mountains as an Indication to the Presence of Mountain Roots:

Gravitation is a universal force of attraction acting between all material bodies. This is expressed by Newton's law of gravity as follows:

$$F = \frac{Gm_1 m_2}{d^2}$$

where F is the gravitational force acting between masses m^1, and m^2, separated by distance d , and G is the universal constant of gravity. This means that the greater the mass of either body, the greater the force of attraction; and the farther apart they are, the less it is.

Consequently, a landmass standing high above its surroundings should exert a sideways gravitational attraction that could be computed and measured. A simple way for measuring such attraction makes use of a plumb bob suspended on a plumb line. Like every other material object on Earth, the freely

suspended bob is pulled down by gravity (as every material body on Earth has a weight or a downward force of gravity proportional to its mass, which the Earth's mass exerts on it). On the surface of a perfect sphere with uniform density, the freely suspended bob would be pulled straight down, and the plumb line would point directly towards the center of the sphere. But the Earth is neither a perfect sphere, nor has a uniform density for the rocks that constitute its crust. Moreover, wherever there would be highly elevated landmasses on the surface of the Earth, the freely suspended plumb line would be deflected towards such high structures as the bob will be attracted by their concentration of mass. Nevertheless, it has always been observed that the actual amount of the sideways gravitational attraction is much less than its calculated value.

In 1749, Pierre Bouguer noticed that plumb bobs were deflected by mountains in the Andes chain, but by amounts much less than the calculated values for such a large mass.

A century later, F. Petit (1849) mentioned that the plumb bob appeared to be deflected away from the Pyrenees Mountains. Similar discrepancies between calculated and measured values of sideways gravitational attraction of mountains were also observed in the middle of the nineteenth century by British surveyors in India under the direction of George Everest. The Himalayas did not exert the gravitational pull they ought to do with their gigantic mass. Knowing the size of the mountain range and the average density of its rocks, its mass could be easily estimated. Using Newton's law of gravitation, it is easy to calculate the expected amount of attraction force the mountain range would exert on the plumb bob. In the case of the Himalayas,

the actual gravitational attraction was found to be only one third of the calculated value, assuming that the mountains have the same average density as the surrounding terrain and that they are resting as a dead load on the Earth's crust.

The fact that the measured attractive force of the Himalayas was only one third of what would be expected from the surface mass of this mountain range came to be known as the Indian Puzzle, and J.

H. Pratt (1855) presented a paper to the Royal Society of London in which he outlined the problem, without making any attempt to explain it.

Only two months later, G. B. Airy (1855) submitted to the same society a solution to this puzzle. He (op. cit.) regarded the Earth's crust as having the same density everywhere and suggested that differences in elevation resulted from differences in the thickness of the outer layer. Moreover, he suggested that the enormously heavy mountains are not supported by a strong rigid crust below, but they "float" in a "sea" of denser rock.

In other words, the excess mass of the mountains above sea level is compensated by a deficiency of mass, less than the surrounding rocks below this datum, produced by a downward extension of the light rocks that constitute mountains in the form of roots. The "mountain root" provides the buoyant support in a manner similar to all floating bodies. In his own words, Airy (op. cit.) mentioned: "... the state of the Earth's crust lying upon lava may be compared with perfect correctness to the state of a raft of timber floating on water; in which, if we observe one log whose upper surface floats higher than the upper surface of

others; we are certain that its lower surface lies deeper in the water than the lower surface of the others."

From the above quotation it is obvious that Airy simulated the Earth's crust to a light, rocky cover, floating on a more dense, liquid substratum.

The hydrostatic equilibrium was said to be achieved by the floating of the less dense material in the denser substratum, with variable depths of compensation. In this way, the maintained state of equilibrium between positive topographic features (such as mountains, plateaus and continents) and negative ones (such as oceanic trenches, troughs and basins) could be easily understood. All positive structures on the surface of the Earth are believed to have roots (like icebergs) and are floating in a denser material. Such a conclusion has since been supported by both seismic and gravity data, as well as by geologic mapping and has been called "the roots of mountains hypothesis." Now it deserves a much higher status in the scientific hierarchy than a mere hypothesis.

It took Pratt four years to present an alternative hypothesis, suggesting that all portions of the Earth's crust have the same total mass above a certain uniform level which he called "the level of compensation" (cf. Pratt, 1859). Consequently, topographic features that are higher than their surroundings (such as mountains) are expected to have a proportionately lower density.

Thirty years later, C. E. Dutton (1889) introduced the term "isostasy," suggesting that different portions of the Earth's crust should balance out, depending on differences in their volume and specific gravity. In his own words, Dutton (op. cit.) stated: "If the Earth were composed of homogeneous matter its normal

figure of equilibrium without strain, would be a true spheroid of revolution; but if heterogeneous, if some parts were denser or lighter than others, its normal figure would no longer be spheroidal. Where the lighter matter was accumulated there would be a tendency to bulge, and where the denser matter existed there would be a tendency to flatten or depress the surface. For this condition of equilibrium of figure, to which gravitation tends to reduce a planetary body, irrespective of whether it be homogeneous or not, I propose the name isostasy (from the Greek isostasios, meaning "in equipoise with;" compare isos, equal, and statikos, stable). I would have preferred the word isobary, but it is preoccupied. We may also use the corresponding adjective isostatic. An isostatic Earth, composed of homogeneous matter and without rotation, would be truly spherical ..."

The resolution of the problem of deficiency of gravitational attraction of mountains did not only lead to the concepts of both isostasy and mountain roots, but also introduced gravity surveying as a method for detecting mass variations in the subsurface of the Earth's crust by their corresponding gravity anomalies.

Gravity surveying has since indicated that the gravity anomaly is strongly negative where the Earth's crust thickens to provide buoyant support for mountains. What causes the negative anomaly in these topographically high places is the mass deficiency due to the displacement of denser mantle material by the less dense crustal root. Similarly, the high positive gravity values over the ocean basins signify the presence of excess mass as dense mantle rock is much closer to

the surface here. This feature has been called "antiroot" and it mirrors the "negative" topography (water instead of rock) of the ocean basin. The Appalachians show a modest negative anomaly, which indicates that they have a shallow root. This is appropriate for an old mountain system; its root (and ganomaly) is disappearing as its topography erodes away (Press & Siever, 1982, p. 437). These authors (op. cit., p. 438) also added: "Actually, the concept of isostatic compensation with its notions of "floating continents" and still higher floating mountains was discovered from gravity observations such as these. But contributed much to our understanding by clearing up such questions as where the mass deficiencies are located and whether compensation involving crustal roots or compensation via low-density mantle is the isostatic mechanism responsible for them. Low-density mantle seems to go with a tectonic setting that includes recent volcanism, higher heat flow, and low seismic velocities - which implies, perhaps, a partially molten mantle directly below the Moho."

Indeed, seismic evidence has indicated that the Earth's lithosphere is floating on a more dense and viscous substratum (the low velocity zone) and that the Earth's surface is in isostatic balance, just like the logs on water or the columns on a liquid substratum. In other words, the surface features of the Earth's crust are balanced by internal inequalities of density. This explains why high mountains are underlain by deep roots of low density, and why rocks under ocean basins are denser than continental ones. It also explains why the mountains' roots are usually several times the elevation of the mountains above sea level (Text.Fig. 1).

Nevertheless, abnormal elevations and depressions are rather limited in their areal extent on the surface of the present Earth. Most of the Earth's crust is currently occupied by two levels, the continents and the ocean floors. Moreover, the difference between the highest mountain peak (Everest = 8848 m above sea level) and the lowest oceanic deep on the surface of the Earth (the Marianas deep = 10867 m below sea level) is slightly less than 20 km (= 19,715 km). Compared with the equatorial radius of the earth (= 6378 km), such elevation difference is only 0.3%, which clearly indicates that all the topographic features on the surface of the Earth are very slight, in comparison with the dimensions of our planet, yet they are instrumental for the stability of its surface, for the rotational stability of the whole earth, and for making it a suitable abode.

B. Evidence in Support of the Fact That the Surface of the Earth Is in a State of Isostatic Equilibrium:

A vast quantity of evidence, accumulated over the last century, substantiates the fact that the Earth's surface is in a state of isostatic equilibrium. Whenever such equilibrium is disturbed, isostatic readjustment starts to take place immediately until the equilibrium is restored, although the rate of such readjustment is believed to be very slow (in the order of a few centimeters per year).

Firstly, it has always been observed that whenever weight is added to the Earth's crust, it responds by subsiding (isostatic subsidence), and that whenever weight is removed it responds by bucking up or uplifting (isostatic rebound). The former case

can be demonstrated by the effect of thick accumulations of ice on land, of huge water and sediment accumulations in front of dams on the surrounding area, or by the accumulation of thick volcanic material around some recent volcanoes, while the second case can be illustrated by the effect of melting of thick ice sheets since the beginning of the Holocene on areas that were covered by thick accumulations of ice during the last great Ice Age.

When the Hoover Dam was built on the Colorado River in the 1930s, the impounded waters of Lake Mead (and to a lesser degree the millions of tons of sediments collected by it) caused regional subsidence and a marked increase in seismic activity.

Similarly, when continental glaciers occupied large areas of both North America and Europe during the Pleistocene Epoch, the added weight of the 2-3 km - thick ice sheets caused downwarpings in the Earth's crust. However, with the advent of the Holocene (about 10,000 years ago), the climate became warmer, the ice sheets started to melt, diminishing its weight gradually, and the Earth's crust started to rise in order to regain isostatic equilibrium. In this process of isostatic rebound, uplifting of as much as 330 m has occurred in the Hudson Bay region during the last 8000 to 10,000 years (cf. King in Wright and Frey, editors, 1965). During the same period, a rise of about 100 m in the Fennoscania (Finland/Scandinavia) region has taken place, and it is calculated that it will continue to rise for another 200 m before isostatic equilibrium is attained (Sauramo, 1965). Evidence of such uplift is well recorded in the form of successive beaches around both the Hudson Bay and the Baltic Sea.

This is simply because of the fact that the less dense lithosphere (about 100 km - thick) is believed to float on top of the denser and more easily deformed, plastic asthenosphere. Again, the fact that the continental crust is much thicker (30-40 km) and has a smaller density (2.7 gm/cm3) than that of the oceanic crust (which is only 5 km thick and has a density of 2.9 gm/cm3) can explain why continents are elevated above the ocean basins. Consequently, both the stability of the gravitational force and its manifestation in the law of flotation must play an important role in determining the elevation of land on the Earth's surface. This can easily explain why mountains do stand high and have deep roots extending into the dense, viscous asthenosphere (below the lithosphere), a conclusion that has been confirmed by both seismic and gravitational data.

Secondly, the fact that mountains do stand high because they have deep roots floating in a denser and more viscous material, and that in the same manner both continents float higher than the denser and thinner oceanic crust, and the lithosphere floats on the asthenosphere (or low-velocity zone) is supporting evidence for the continuous need of isostatic readjustment.

Thirdly, gravity anomalies are taken to support the play of isostatic readjustment as it points to either deficiencies or excess mass in the lithosphere, and hence to expected rises or falls of the land surface to attain isostatic equilibrium. Areas of the Earth's crust not in isostatic equilibrium are indicated by the presence of gravity anomalies, which are departures from the predicted value of "g" for these areas. Vertical movements occur in the Earth's crust in response to changing loads exerted on it, because in the absence of any applied force, the crust is said to

be in isostatic equilibrium. These movements may be accommodated by lateral movements of matter within the upper mantle, or by phase changes in this upper part of the mantle.

Fourthly, the exposure of old mountain roots in the hearts of continents is taken to support the process of isostatic readjustment. As the mountain range is being eroded, it continues to be uplifted to maintain its isostatic equilibrium. This type of vertical movement is generally known as epeirogeny (in contrast to orogeny which mainly involves horizontal forces and tends to be more localized areally). Epeirogeny can continue at pace with erosion until the mountain root becomes exposed to the Earth's surface. This can explain why older mountain ranges such as the Appalachians or the Urals are not so lofty as the much younger Andes, Alps or Himalayas. Such younger mountains are still being uplifted-in part-by the original mountain building forces as well as by isostatic readjustment (cf. Cazeau and others, 1976 p. 411).

In such a struggle between internal building processes and external destructive ones, erosion, finally wins the battle over the mountain range when enough depth of the mountain root is no more left to raise the mountain range by isostasy. When the mountain root reaches the same thickness as the remainder of the continental interior adjacent to it (a more or less equilibrium thickness) epeirogeny ceases to act, and the old mountain system becomes a part of the stable craton, adding to the size of the continent (Text-Fig. 2).

When a mountain system or chain has finally been worn down to a region of low hills or a plain, evidence of its former existence is still preserved in its rocks. The folded and faulted

sedimentary rocks would have been completely eroded, leaving exposed only metamorphic rocks intruded by igneous masses; but these show clearly by their intense folding and crushing that they once formed the roots of a mountain range (cf. Beisser & Krauskopf, 1975, p. 188).

C. Mountains in the Framework of Modern Earth Sciences:

In the framework of modern Earth Sciences, mountains, both inwardly and outwardly, are greatly thickened parts of the Earth's crust that have been produced by various building (and/or deformational) processes. Such marked landforms do not only stand high above the surface of the Earth, but also extend deeply into the supporting material below. Mountains remain raised above their surroundings by floating into the more dense and viscous substratum, with deeply immersed roots that can reach up to several times their elevations above the ground surface depending on the average density of the rocks from which the mountains are composed and that of the supporting material in which the mountain roots are immersed (e.g. the Sierra Nevada of eastern California). Such buoyancy helps mountains to remain in a state of isostatic equilibrium with their surroundings and can account for a large number of observed phenomena. Indeed, both seismic and gravitational studies indicate that the continental crust is thickest under the highest of mountains and thinnest under the most depressed continental areas, and that the oceanic crust is always much thinner and has a slightly greater density.

Individual mountain elevations can run in belts or ranges several thousands of kilometers long, and a succession of ranges can form a mountain system, several hundreds of kilometers wide. These show evidence of enormous forces that have deformed large sections of the Earth's crust by folding, faulting, overthrusting, both intrusive and extrusive magmatism (plutonism and volcanism) and by metamorphism. The name given to the group of processes which collectively produce mountains is orogenesis (from the Greek oros = mountain, and genesis = to come into being).

As mentioned above, a mountain range is composed of a number of more or less parallel ridges, all formed by the deformation of rocks originally deposited in a single sedimentation basin, while a mountain system is composed of a number of parallel or consecutive ranges formed by the simultaneous deformation of different basins. A mountain chain consists of two or more mountain systems of the same general trend and elevation, while a cordillera is formed of several chains in the same part of a continent.

Various theories have been put forward to explain how mountains are built, but none was enough to explain the whole range of geologic processes involved. However, less than two decades ago, it became obvious that the younger mountain belts of the Earth (Text Figs. 3, 4) appear to be related to global tectonics (i.e. to the movement of large plates of the Earth's lithosphere on the underlying low-velocity zone or asthenosphere). In the framework of such large-scale tectonics, orogeny occurs primarily at the boundaries of colliding plates, where marginal sedimentary deposits are crumpled and both intrusive and extrusive magmatism, together with various grades

of metamorphism are initiated. Nevertheless, a brief survey of the known kinds of mountains should precede any attempt to explain how mountains are formed.

(a) Kinds of Mountains

As mentioned above, individual mountains within a range, system chain, or cordillera can be related to individual geological structures such as folding, faulting, igneous activity, or to a combination of such events. However, the development of a whole chain of mountains (orogenesis) has to be interpreted in terms of much larger tectonic episodes (megatectonics or global tectonics).

Again, regardless of their mode of formation, the present shape of individual mountains is also related to a large number of factors such as its age and the stage it has reached in the mountain-building cycle, the climatic conditions under which it has existed and the resistance of its exposed rock types to erosion. Indeed, mountains are born, grow, achieve youth, maturity and old age, then they are worn down and finally disappear. The oldest known rocks on the Earth's surface today (Text Figs, 5, 6) are believed to be the roots of some ancient mountains. These currently form the relatively stable cratons or shield areas of the continents.

According to their geometry, structure, rock composition, and/or age, four main kinds of mountains have been recognized; these include: volcanic mountains, folded mountains (or fold belts), fault-block (or block-faulted) mountains and erosional (or upwarped) mountains (Text Figs. 7, 8). These are, indeed, successive stages in the development of mountains, besides

being distinctive types. Volcanic mountains represent the initial stage in the development of such gigantic landforms, while folded mountains represent the peak of youthfulness and maturity, and erosional (or upwarped) mountains represent the old age. Fault-block mountains can be produced at any of these stages, but, nevertheless, have traditionally been treated as a specific type of mountain. These four types or stages in the development of mountains can briefly be described as follows:

1) ***Volcanic Mountains*** : (such as Kilimanjaro of East Africa, Paricutin of Mexico, Mauna Loa of Hawaii, Vesuvius of Italy, Fujiyama of Japan, etc.: Text fig. 9): These are the simplest known mountains and are usually in the form of isolated peaks, constructed from accumulated lava flows, pyroclastic debris and other extruded igneous rocks that might have piled up rapidly (in only a few years), or might have grown slowly (over thousands or even millions of years).

   Such piling-up of eruptive material can take place around volcanic vents producing cinder cones (such as Vesuvius, near Naples) or elsewhere, producing volcanic mountains. It can also flow out at the surface and consolidate in the form of a broad, gently sloping flat topped, volcanic dome, usually several tens or hundreds of square kilometers in extent, being chiefly built of overlapping and interfingering basaltic lava flows (volcanic shield). These can gradually grow into volcanic mountains such as Mauna Loa in Hawaii (which rises from a depth of 4270 m below sea level to a height of more than 3960 m above sea level), Kilauea of the same island, and the geat basaltic accumulations of Iceland (Text Figs. 10, 11).

Volcanic mountains seem to have their origins connected to deep faults that extend below the Earth's crust to the mantle which supplies their building materials. In other words, volcanic mountains are directly related to deep rifting in the Earth's crust and hence are considered to represent the earliest stage in the development of a mountainous chain.

In terms of global tectonics, most of the volcanic types of mountains are believed to be associated with movements near the boundaries of lithospheric plate (Text Fig. 4). These are created as a result of downward, subplate disturbances (e.g. the Aleutian and the Cascade volcanoes: Text Figs. 12, 13) or as a direct consequence to the pulling apart of lithospheric plates at mid-oceanic rifts (e.g. both Kilimanjaro and the Kenya Mountains which are both directly related to the East Africa rift system: Text Fig. 14).

Indeed, active volcanoes are most abundant in narrow belts, particularly in the island areas that rim the Pacific Ocean (where it is believed that the Earth's crust is currently being consumed by descending into the mantle), as well as along mid-ocean ridges (where new oceanic crust has been steadily produced since at least the time between 150 and 200 million years ago).

The Aleutian Islands are peaks of volcanic mountains that stretch out for 3200 km along the circumference of a circle centered at 62 40` N and 178 20` W Island arcs festoon the western borders of the Pacific Ocean, with great oceanic deeps (trenches) on the outside curve of many of them.

Similarly, many geologists believe that mid-ocean ridges are true volcanic mountain ranges. These attain heights of as

much as 1800 m above the ocean bottom and are covered - in places - by up to 2700 m of water. Nevertheless, in the framework of plate tectonics, such ridges are believed to have "antiroots" rather than roots, and hence their inclusion among mountains can be strongly debated. Antiroots are accumulations of higher-density material in the suboceanic crust that compensates for the low density of oceanic water. These are injected upwardly from the underlying upper mantle by either convection currents or thermal plumes.

More than 64,000 km of mid-ocean ridges have - so far - been mapped around mid-ocean rift valleys. These have been pouring out fresh basaltic material on both sides of such ruptures in the Earth's crust, since the early days of their initiation, to build-up new oceanic crusts. The youngest oceanic crust will always be around deep rift valleys and will steadily push older crusts away from it. The oldest existing oceanic crust does not exceed the Mesozoic in age, and is currently being consumed at the convergent edges of the plates with rates almost equivalent to the rate of producing new oceanic crust.

Few volcanic mountains are found on the continents such as the isolated peaks of Ararat (5100 m), Etna (3300 m), Vesuvius (1300 m), Kilimanjaro (5900 m), and Kenya (5100 m). These are also associated with intra-cratonic, deep rift systems that communicate with the upper layer of the Earth's mantle (Text Figs. 9, 14, 18).

2) ***Folded Mountains (or Fold Belts)*** : These represent the peak of the development of mountain belts, and hence are represented by the great mountain systems of the world such

as the Andes, Carpathians, Urals, Alps. Juras, Himalayas, etc. (Text Figs. 3, 4, 6, 7). Such mountain systems normally comprise broad belts of varied rock types and of structural patterns that involve folding, faulting, over-thrusting and igneous activity. Faults are particularly numerous along the borders of these highly folded belts. Some are normal faults, but the majority are low-angle thrust faults that extend for hundreds of kilometers, pushing gigantic masses of rock over one another for many kilometers (overthrusting).

Field observations clearly indicate that the development of folded mountains was normally preceded by the formation of geosynclines. A geosyncline is a large basin in the Earth's crust, usually scores of kilometers wide and hundreds of kilometers long, with sediments of marine origins that do not usually exceed the 300 m depth, that alternate with layered volcanic accumulations in complexes of more than 15,000 m thick. Consequently, geosynclines are believed to have been deeply rifted, slowly and steadily subsiding basins to keep pace with the accumulation of such thick sections of sediments and layered volcanics. The formation of a geosyncline must then involve a slow, and continuous downwarping of the Earth's crust with the continuous deposition of sediments, and a near access to molten basalts. Here, the theory of plate tectonics can provide the clue to the formation of a geosyncline. Seismic evidence from many earthquakes confirms the motion of oceanic plates away from mid-oceanic rifts towards and under other plates where inter-oceanic island-arc-trench systems, or oceanic/continental trench systems are formed and the lithosphere of the subducting (or under-gliding) plate is gradually consumed into the mantle at

a rate equal to sea-floor spreading. Plate subduction can account for the formation of oceanic trenches, and the partial melting of the descending plate can explain both the availability of molten magma and the formation of volcanic arcs. Such oceanic trenches are ideal sites for the geosynclinal accumulation of sediments, and hence, geosynclines are believed to have developed in such structurally mobile belts, where subsidence is not only produced under the weight of accumulating sediments, but is also maintained by the gradual sliding of one lithospheric plate below another. When the oceanic plate between two continental masses is completely subducted and consumed, continent/continent collision takes place, forming folded mountains and the highest peaks on earth.

The sediments accumulated in a geosyncline eventually sink to levels where they become surrounded by denser, more viscous rocks, and their own buoyancy sets a limit to the depth to which they can sink under their own weight. At that point, the whole system becomes isostatic, and the thickness of the sediments cannot be increased just by load.

Both folding and faulting occur continuously while sediments are accumulating. Rocks at the surface are brittle and hence, they break before they flow, but under deep burial, they become plastic and change both their shape and volume by folding and/or slow flowing. When sediments are buried deep enough, they melt. Expansion of such molten rocks causes the whole overlying mass to rise, and their cooling will produce basement rocks that often participate in the folding process (cf. Billings, 1960).

Near the edges of the geosyncline, the rocks are squeezed upward and outward along great thrust faults, while in the central area they are pushed upward to form an inter-montane plateau. Evidence of preconsolidation folding supports the contention that the mountain-building forces were active during sedimentation. Indeed differential downwarping could have produced folding while deposition was in progress, but at this stage, the dominant forces were probably mainly vertical. Thrust faulting along the margins of the geosyncline could have been initiated by a bordering zone of differential subsidence, but as active horizontal and tangential compressive stresses are usually late in the geosyncline's history (as a result of the collision of plates) they may be the main cause of overthrusting. Such stresses finally elevate the already deformed strata to mountainous heights. Modem examples of geosynclinal zones growing slowly into mountain ranges are thought to exist today between the Pacific border of Asia and arcs of volcanic islands off the continental coast (Text Fig. 12).

From the above mentioned discussion, it is obvious that the major mountain systems have evolved as a result of the movement of lithospheric plates. At the boundary of two such plates, one plate can move down relative to the other, a geosyncline develops and island arcs are built by the piling up of eruptive volcanic material initiated by subduction. Later, the geosynclinal infilling of sedimentary and volcanic rocks rises to form a mountainous chain. As it rises, folds and faults develop either through squeezing (the horizontal-tectonics hypothesis) or through gravity sliding of material away from the rising welt (the vertical - tectonics

hypothesis) or by both. Mountain ranges could also result from the collision of two continents being rafted along on their lithosphere conveyor belts (e.g. the Alps and the Himalayas). In both cases, folded mountain ranges were not formed by the deformation of only one geosyncline, but rather by the deformation of many.

Present-day mountain ranges were definitely much higher. These were worn down over time and were left as erosional remnants of the original, sharply folded and faulted uplifts. Isostatic rebounds for the whole mountain range would also intervene to compensate for erosion and keep the isostatic adjustments. This can go on until the mountain roots are exposed to the surface, attain the thickness of the surrounding lithosphere and the mountain chain is almost completely levelled.

3) ***Fault-Block Mountains (Block-Faulted Mountains)*** **:** Such mountains are formed by uplifts of the Earth's crust along steep dipping or almost vertical faults. Differential tilting of blocks of the Earth's crust along areas of separation such as rifts can produce fault-block (or block-faulted) mountains. These occur in many parts of the world, frequently adjacent to incipient oceans (such as the Red Sea) or at the periphery of fold belts. Subsequent to folding and low-angle thrust faulting in such belts, a period of steep block faulting produces fault-block mountains at the periphery of the folded mountain range.

Fault-block mountains are large, uplifted sections of the Earth's crust that are bounded by faults in the form of alternating horsts and grabens (e.g. the Great Basin and

Range province of Oregon, the Sierra Nevada of California, the mountain ranges that border both the Red Sea rift and the rift valleys of East Africa, etc.). Their rocks may be totally crystalline, igneous and metamorphic complexes or may carry a thin or a thick sedimentary cover. The sedimentary cover, being originally deposited in a geosyncline, can sometimes be folded during an earlier cycle of deformation, before the region was broken up into blocks and uplifted by successive movements along the different planes of faults over millions of years to attain mountainous heights. In the North American Cordillera (along the western border of North America), the fault-block mountains began to be elevated about the same time as their neighboring folded mountains and plateaus, indicating that regional deformative forces were acting (cf. Leet and Judson, 1971, p. 470).

Many geologists believe that block-faulting is due to either stretching or relaxation in the later phases of a geosyncline/mountain-building cycle. But, according to the theory of plate-tectonics, large scale rifting may be due to intraplate ruptures, followed by the pulling apart of the ruptured lithospheric plate to diverge away from each other as two new separate plates (such as the splitting of the Arabian/Nubian plate). Fault-block mountains can also be produced at a later stage in the development of subdued folded mountains, when faulting can provide the necessary elevation of the mountainous range.

4) ***Upwarped (or Erosional) Mountains*** **:** These are the erosional remnants of previously existing mountain ranges and owe their present heights and appearances to broad upwarpings of

the Earth's crust as a result of isostatic adjustment (e.g. the Ozarks, Adirondacks, Appalachians, Rockies, Black Hills, the Highlands of Labrador, etc.). When the old mountain chains were worn down by erosion and reduced to subdued topographies, isostatic re-adjustment brought them to their present-day elevations. Such subdued elevations represent the final stage in the history of a mountainous chain, before they are almost completely levelled and added to a previously existing craton.

(b) Origin of Mountains

Two main hypotheses were put forward to explain the formation of mountains: the vertical - tectonics hypothesis which claims the predominance of vertical movements in the Earth's crust, and the horizontal-tectonics hypothesis, which states that the major land movements responsible for the building of mountains are primarily horizontal in nature and are directly connected with both plate tectonics and the drifting of continents.

Both hypotheses, however, recognize the close association of orogenesis with geosynclines. As previously mentioned, geosynclines are very large, elongated troughs, several thousands of kilometers long and several hundred kilometers wide, that have been infilled with very thick accumulations of both sediments and layered volcanics (more than 15,000 m thick). Such infill becomes later squeezed and uplifted to form mountains, with or without a crystalline core of igneous and metamorphic rock.

The vertical-tectonics hypothesis postulates that thermal expansion can cause gravity faulting (or sagging) to produce

geosynclines in the form of half grabens or full grabens, while plate-tectonics assume that such troughs are formed by the subduction of one lithospheric plate below another as a result of a driving force in the underlying mantle such as convection currents or thermal plumes (Text-Figs. 1-9).

The central idea of plate tectonics is that the solid, outermost shell of the Earth (the lithosphere) is riding over a weak, partially molten, low velocity zone (the asthenosphere). Continents are looked upon as raft-like inclusions embedded in the lithosphere, while only a thin crust (5 km thick) tops the lithosphere in ocean basins (Text-Figs. 15-19). The thickest continental crust, about 70 km, is reported to lie beneath the Alps (cf. Press and Siever, 1980).

The lithosphere (about 100 km thick) is broken up into about 12, large, rigid plates by rift systems (Text-Fig. 21). Each of these plates has been moving as a distinct unit, diverging away or converging towards each other and slipping past one another.

Along divergent junctions, plates spread apart, being accompanied by intensive volcanicity and earthquake activity. The resulting space between the receding plates is filled by molten, mobile, basaltic material that rises from below the lithosphere. This basaltic magma solidifies in the cracks formed by the rift, producing new sea-floor material that adds to the edges of the separating plates and hence, the name "seafloor spreading" for the whole process which is continuously repeated over and over again.

Most basaltic magmas are believed to originate from the partial melting of the rock peridotite, the major constituent of the upper mantle. Since mantle rocks exist under high

temperature and high pressure, melting most often results from a reduction in the confining pressure, although the influence of increasing temperature cannot be excluded. This can result from the heat liberated during the decay of radioactive elements that are thought to be concentrated in both the upper mantle and the crust.

Along convergent junctions, plates collide against each other, producing volcanic island-arcs, deep-sea trenches, both shallow and deep earthquakes and volcanic eruptions (Text-Figs. 15-19). In the framework of plate tectonics, orogeny occurs primarily at the boundaries of colliding plates, where marginal sedimentary deposits are crumpled and both intrusive and extrusive magmatism (volcanism) are initiated. However, mountain belts formed at such junctions differ with the different rates of spreading as well as with the nature of the leading edges of the colliding plates (continental or oceanic).

When the abutting edges are ocean floor and continent (Text-Fig. 15), the heavy, oceanic lithosphere descends beneath the lighter, continental one to subduct into the underlying mantle. This downbuckling is marked by an offshore trench, while the edge of the over-riding plate is crumpled and uplifted to form a mountain chain parallel to the trench. Great earthquakes occur adjacent to the inclined contact between the two plates, and increasing in depth with the increase in the downward movement of the descending plate (Text-Fig. 22), while oceanic sediments may be scraped off the descending slab and incorporated into the adjacent mountains. Such zones of convergence, where the lithosphere is consumed are called subduction zones. Here, the lithospheric material is consumed in equal amount to the production of new lithosphere along the

zones of divergence. Rocks caught up in a subduction zone are metamorphosed, but as the oceanic plate descends into the hot mantle, parts of it may begin to melt, and the generated magma may float upwardly, in the form of igneous intrusions and/or volcanic eruptions. The production of magma in the subduction zone may be a key element in the formation of granitic rocks, of which continents are mainly composed.

Granitic magmas are thought to be generated by the partial melting of water-rich rocks, subjected to increased pressure and temperature. Therefore, burial of wet, quartz-rich material to relatively shallow depths is thought to be sufficient to trigger melting and generate a granitic magma in a compressional environment characterized by rising pressures. Most granitic magmas, however, loose their mobility before reaching the surface and hence, produce large intrusive features such as batholiths.

Andesitic magmas are intermediate in both composition and properties between the basaltic and the granitic magmas. Consequently, both andesitic intrusions and extrusions are not uncommon, but the latter are usually more viscous and hence, less extensive than those produced by the more fluid, basaltic magma. A single volcano can, therefore, extrude lavas with a wide range of chemical compositions and hence of physical properties.

Again, when an oceanic plate with a continent at its leading edge collides with another plate carrying a continent (Text-Fig. 16), convergence (accompanied by the gradual consumption of the oceanic lithosphere by subduction) gradually closes the oceanic basin in between, producing magmatic belts, folded

mountains and mÈlange deposits on the over-riding continental boundary. This can continue until the two continents collide, when the plate motions are halted, because the continental crust is too light for much of its composition to be carried down to the mantle. Here, the descending oceanic plate may break off, with the complete cessation of subduction at the continent/continent suture, but this can start up again, elsewhere on the colliding plate. Such continent/continent suture is marked by lofty mountainous chains, made up of highly folded and thrust-faulted rocks, coincident with or adjacent to the magmatic belt. Both giant thrusting and infrastructural nappes lead to considerable crustal shortening and are accompanied by much thickening of the continental crust. An excellent example of continent/continent collision is the Himalayan chain, which began forming some 45 million years ago. This magnificent mountainous chain, with the highest peaks on the surface of the Earth, was created when a lithospheric plate carrying India ran into the Eurasian plate in the Late Eocene Epoch. This can explain how the very thick root underlying the Himalayas was formed.

The plate tectonic cycle of the closing of an ocean basin by continued subduction of an oceanic plate under a continental one until a continent/continent collision takes place and an intra-continental (collisional) mountain belt is formed, has been called the "Wilson cycle," after J.T. Wilson, who first suggested the idea that an ancient ocean had closed to form the Appalachian Mountain Belt, and then re-opened to form the present-day Atlantic Ocean. As partly mentioned by Dewey and Bird (1970), any attempt to explain the development of mountain belts must account for a large number of common

features which are shared by most of the fully developed younger mountain chains such as:

1) Their overall long, linear or slightly arcuate aspect.

2) Their location near the edges of present continents or near former edges of old continents that are presently intra-continental.

3) The marine nature of the bulk of their sediments, and the intense deformation of such sediments.

4) Their frequent association with volcanic activity.

5) Some of their thick sedimentary sequences were deposited during very long intervals, in the complete absence of volcanicity.

6) Short-lived, intense deformation and metamorphism, compared with the lengthy time during which much of the sedimentary succession of mountain belts was deposited.

7) Their composition of distinctive zones of sedimentary, deformational, and thermal patterns that are in general, parallel to the belt.

8) Their complex internal geometry, with extensive thrusting and mass transport that juxtaposes very dissimilar rock sequences, so that original relationships have been obscured or destroyed.

9) Their extreme stratal shortening features and, often, extensive crustal shortening features.

10) Their asymmetric deformational and metamorphic patterns.

11) Their marked sedimentary composition and thickness changes that are normal to the trend of the belt.

12) The dominantly continental nature of the basement rocks beneath mountain belts, despite the fact that certain zones in these belts have basic and ultrabasic (ophiolite suite) rocks as basement and as upthrust slivers.

13) Presence of a thrust belt along the side of the mountainous chain closest to the continent, usually with thrust sheets and exotic blocks (or allochthons).

14) Presence of mèlange belts (composed of mappable rock units of crumpled, chaotic, contorted and otherwise deformed, heterogeneous mixtures of rock materials, with abundant slumping structures and ophiolitic complexes).

15) Presence of a complexly deformed metamorphic core, with severe metamorphism, magmatization and plutonic intrusions.

16) Presence of magmatic belts of both plutonic, hypabyssal and volcanic igneous activity.

17) Presence of folds of several stages and with unified or divergent trends.

18) Presence of block faulting, especially at the peripheries of the mountainous chain.

19) Presence of deep roots that are proportionately related to both the mass and elevation of the mountainous range, and can be as deep as 5 times the mountain's height, or even more.

These features are clearly suggestive of geosynclinal deposition, or deposition in mobile belts that are generally referred to as orthogeosynclines and are typically produced by the subduction of an oceanic plate below a continental one. Orthogeosynclines are usually separated into eugeosynclines (characterized by intensive volcanicity) and miogeosynclines (distinguished by being non-volcanic).

Eugeosynclinal belts (with their basic lavas, radiolarian cherts and graywackes, intermediate lava and fragmental volcanic rocks, as well as other sedimentary, volcanic and plutonic rocks that are metamorphosed to varying degrees) usually characterize the central cores of mountain systems. However, these can be notably narrow and may even be absent in some of the major mountains, probably due to severe tectonism in recurring phases of orogenesis. Extrusive lavas and agglomerates that fringe eugeosynclinal belts are identical to those currently being deposited in modern island arcs. Thick sequences of shallow-water sedimentary rocks without volcanic material (characteristic of miogeosynclines) sometimes occur in a belt parallel and adjacent to the eugeosynclinal belt. These usually occur on that side of the mountain chain nearer to the old cores of continents (known as the continental cratons), which are themselves believed to be old mountain roots.

Such features of youthful mountains have strongly supported the contention that the present-day, paired island arc/trench systems, with their intensive seismicity and volcanicity, are quite probably mountain belts in the process of formation.

Miyashiro (1967) observed that the mountainous islands of Japan belonged to an old island arc/trench system that had been

compressed and subjected to metamorphism and uplift during the later part of the Mesozoic era. These mountains exhibit a pair of different metamorphic belts parallel to the length of the islands and adjacent to one another. On the Pacific side, the main outcrops are schists containing minerals indicative of formation at relatively low temperature but high pressure (e.g. glaucophane, aragonite, lawsonite), and without any evidence of granitic basement. On the western side of the islands, the other belt has granites and metasediments with minerals indicative of relatively high temperature and low pressure (e.g. sillimanite).

Such paired metamorphic belts, also formed during a late Mesozoic orogeny, were found elsewhere around the Pacific (e.g. in both New Zealand and California), with the "glaucophane-schist" (or "blue-schist") belt always occuring on the ocean side, and the high-temperature, metamorphic belt (the "sillimanite-schist" belt) on the continental side.

The "blue-schist" belt is interpreted to have formed under ocean trench conditions, where the required low temperature and high pressure are likely to be obtained. Similarly, the high temperature metamorphic belt is debated to represent uplifted island arcs, where high heat flows must have been obtained. This is especially true where a collisional suture zone marked by blue schist ophiolite mèlanges is recorded (cf. Dickinson, 1970, 1971; Dewey and Bird, 1970, Dewey, 1971 and Hallam, 1973).

Stemming from this, Dewey and Bird (1970) suggested that mountain belts are a consequence of plate evolution and that they develop by the deformation and metamorphism of the sedimentary and volcanic assemblages of Atlantic-type continental margins. These authors (op. cit.) proposed two main

types of mountain building. The first "island arc/cordilleran type," is for the most part thermally driven and develops on leading plate edges above a descending plate (i.e. above a subduction zone) and is marked, by paired metamorphic belts, paired miogeosyncline (continental shelf) eugeosyncline (region between continental shelf edge and trench) relationship, and divergent thrusting. The second "collision type" results from continent/island arc or continent/continent collision. It is for the most part mechanically driven, lacks the paired metamorphic zonation, its metamorphism is dominantly of the low-temperature type ("blue schist" facies) and its thrusting is dominantly towards and onto the consumed plate. This often involves the complete remobilization of basement near the site of collision, and gravity slides further onto the site of the old continental shelf.

Another essential difference between the two types of mountain belts is that the cordilleran type has a dense, basic root (cf. Thompson and Talwani, 1964), probably related to the emplacement of basic intrusions beneath the high-temperature, volcanic, metamorphic axis, while the root of collision mountain belts is sialic and probably results from continental underthrusting and thickening (cf. Dewey and Bird, 1970).

Ophiolite belts usually mark the presence of former zones of subduction between two colliding plates, and are a significant feature of most mountain belts. These are commonly associated with radiolarian cherts which are believed to be of deep marine origin. Ophiolites are said to be well-developed in cordilleran mountain belts and form extensive upthrust regions behind the "blue schist" trench terrains, in the form of huge thrust slices or

slivers of peridotite, gabbro and basaltic pillow lava. The composition and structure of the rocks strongly suggest oceanic crust and mantle which have been forced upwardly into the overlying rocks by the subducting plate. These also occur as smaller, detached rafts in the mèlanges of trenches, representing blocks that might have slid down the inner trench wall, slices of oceanic crust, of upper mantle, or of both, and of seamounts torn off the descending plate. Thick, intensely deformed oceanic sediments might also have been scraped off the descending plate and plastered to the inner trench wall or incorporated into the adjacent mountains. Subsequent uplifts expose the so-called mèlange terrain of highly complicated nature, in which shear surfaces replace bedding as the dominant structural feature.

In collisional mountain belts, ophiolite blocks are extruded from the trench during collision and lie in flysch-mÈlange suture zones that mark the collision "join lines." The composition of ophiolite pillow basalts may be a criterion for distinguishing between the crust of the main oceans (tholeiite and spilite) and the alkalic crust of small ocean basins, if the latter are produced by the separation of arcs from continents (cf. Dewey and Bird, 1970). These authors (op. cit.) concluded that: "Although the cordilleran/island arc and collision mechanisms are probably the fundamental ways by which mountain building occurs, mountain belts are generally the result of complex combinations of these mechanisms." They referred to the evolution of the Appalachian orogen (Bird and Dewey, 1970) which involved Ordovician cordilleran/island arc mechanisms, followed by Devonian continental collision.

Dewey and Bird (op. cit.) also mentioned that the Alpine - Himalayan system has been developing since the early Mesozoic times by multiple collision resulting from the sweeping of microcontinents and island arcs across the Tethyan - Indian Ocean. Similar inland mountain belts such as the Urals, were also looked upon as complex combinations of cordilleran belts, microcontinents, and volcanic arcs, of widely different ages, that became juxtaposed by the closing up of a major ocean basin.

The possibility of expanding and contracting transform offsets of consuming plate margins was mentioned by these authors (loc. cit.) to raise the likelihood of distinctive belts of volcanism, deformation and metamorphism coming to an abrupt termination along the strike of a mountain belt.

From the above discussion it becomes obvious that the two main types of mountain building suggested by Dewey and Bird (1970) which are: the "island arc/cordilleran type" and the "collision type" are no more than successive stages in the mountain-building cycle as each continent/continent collision must be preceded by closing the ocean basin in-between. In other words, collisional mountains represent the final stage in the development of these magnificent landforms, and must be preceded by both the island arc and the cordilleran stages. This is clearly demonstrated by the Himalayan orogeny, which is considered to be the product of a combination of both the cordilleran and the collisional types of mountain building (cf. Athavale; in Tarling and Runcorn, 1973). This author (op. cit.) concluded that "The present boundary between the Indian Plate and the Eurasian Plate is delineated by the belt of ophiolites and colored mèlange rocks separating the 'Tethys' Himalayas from

the Karakoram and Tibetan Plateau region of Central Asia ..." and added: "... the Himalayan orogenic belt has resulted through a combination of the two principal mountain-building processes. The first phase of the Himalayan orogeny, taking place at the junction between the continental margin of the Indian Plate and the Tethyan oceanic crust, during the Upper Cretaceous to Eocene period, could be considered as of the "cordilleran" type. Available geological data appear to indicate that the subsequent phases in the Himalayan orogeny, commencing probably from Late Eocene, were the result of the collision between the Indian and the Eurasian Plate."

Athavale (op. cit.) also reiterated that both Hamilton (1970) and Bird and Dewey (1970) had already evolved similar models for each of the Ural Mountains and the Appalachian chain, respectively.

Consequently, it is here concluded that mountain belts are created along the boundaries of colliding lithospheric plates in three successive stages as follows:

1) The Volcanic Island Arc Stage

This stage is developed in the early phases of collision between two oceanic plates (Text-Fig. 17) or between an oceanic and a continental plate (Text-Fig. 15). Such collision is usually manifested in the formation of a deep oceanic trench above the subduction zone, and a chain of linear or arcuate volcanic islands on the overriding plate, running along the convergent plate boundary. Such a chain of volcanic islands is formed from eruptive magma, derived from the partial melting of the subducted plate, as well as from the displaced

asthenosphere above that descending plate. Both intrusive and extrusive magmas, as well as the sediments admixed with them, produce a magmatic belt in the overriding plate, while in the oceanic trench, a mèlange complex is progressively formed. Over an extended period of magmatic activity, both the size and elevation of the developing arc are progressively increased by the addition of new eruptive material and by the emplacement of new plutons. The arc is also steadily elevated isostatically due to the buoyant nature of the intrusive igneous masses. The emplacement of such large magmatic bodies at high temperatures also leads to the deformation and metamorphism of the surrounding sediments.

In the developed oceanic trench, a thick wedge of highly deformed rocks progressively accumulates parallel to and seaward from the magmatic belt. This complex mèlange is formed of both clastic and deep-water sediments (the latter being scraped off the descending oceanic plate and piled onto the landward side of the trench) and is usually admixed with basic to ultrabasic igneous material (an ophiolite suite). The mèlange rocks are usually metamorphosed to the "blue-schist" facies of high pressure and low temperature metamorphic grade, as some of these trenches can be more than 10 kilometers deep. Continued accretion of the volcanic arc mèlange complex can result in accumulations thick enough to stand above sea level and form islands or submarine ridges that separate "fore-arc basins" between the volcanic arc and the edge of the colliding plate (e.g. the Indonesian Islands). Later deformation of these rocks can produce a mountainous chain similar to the mountains of the Japanese Islands (cf. Miyashiro 1961, 1967).

Island arcs are usually associated with deep-focus earthquakes and negative gravity anomalies. Such arcs can form in at least two ways.

In the first, the subduction zones form initially well offshore, probably between two oceanic plates (e.g. the Aleutian Islands), leaving a "back-arc basin" between the island arc and the continent (Text-Fig. 17). In the second case, the subduction zone initially forms at the continent/ocean border (Text-Fig. 15), where the volcanic arc is formed, then a rift could develop and lead to its separation from the continent (e.g. Honshu Island in the sea of Japan).

It is generally agreed that modern island arcs represent the initial stage in the formation of continental mountain belts. If sea-floor spreading stops at this stage (for one reason or the other), the mountain-building cycle can stop at the mature island arc mountain stage, but if it continues, the following stages can successively be reached.

2) The Cordilleran Mountain Stage

As mentioned above, volcanic island arcs are usually produced at an oceanic/oceanic convergent boundary or at an oceanic/continental subduction zone. In the latter case, plate convergence generates a subduction zone and partial melting of the subducted plate generates the volcanic arc. Since the break between the continental and oceanic lithospheres generally forms seaward, off their actual junction, the volcanic arc often forms a few hundred kilometers out to sea, with a back-arc basin separating it from the continental mass. Further convergence causes the closure of the back-arc basin and the deformation as

well as the metamorphism of its sediments, of the volcanic arc itself and of the mèlange complex accumulating in the oceanic trench. Continued growth of this complex can produce a cordilleran type mountainous chain such as the Andes, by plastering the deformed, back-arc sediments, magmatic belt and mèlange complex to the continental side as well as by crumpling that side of the continent. Subsequent uplifting and erosion can expose a core of crystalline rocks between metamorphosed back-arc sediments on the continental side and a mèlange belt on the oceanic side.

In the case of oceanic/oceanic convergent boundary, the same process can continue until a cordilleran chain of mountains is plastered to the nearest continent floating on the overriding plate (Text-Fig. 17). If no close continents are there, the mountain-building cycle can stop at the volcanic island arc stage. Contrary to this, if the two converging oceanic plates are carrying continents at their distal ends, the continued consumption of the oceanic crust can finally lead to the closure of the ocean basin, the collision of the two continental masses and the further deformation and metamorphism of both the sedimentary and volcanic rocks. This leads to the final stage in the cycle of mountain building, which is represented by the inter-continental collisional mountains (TextFig. 16).

3) The Collisional Mountain Stage

This is the final stage in the mountain-building cycle. Here, collision takes place between two continental masses, after closing the ocean between them, sweeping and squashing whatever microcontinents, island-arcs or cordilleran mountains

that would be in between. In describing such continental collision, Dewey and Bird (1970, p. 2641-2643) mentioned that "The trench-bearing margin may be associated with an existing or developing cordilleran type orogen or with a margin resulting from an island-arc/continent collision ... The structures developed as the Atlantic-type margin is driven onto the trench are likely to be initially similar to those already described for an arc/continent collision, which involve the splintering and thrusting of continental basement to form cores of nappes. Oceanic crust, chert, lutite, and flysch, are squeezed and thrust over lower thrust sheets. Eventually, however, the buoyancy of the underthrust continental rocks prevents further destruction, and the descending plate may break off and sink into the asthenosphere (McKenzie, 1969). At that time a single trench zone of plate consumption will be replaced by cracking and splintering of the lithosphere over a wide area ... Eventually, a new trench is likely to form near the Atlantic-type trailing edge of the collided continent."

"Such change in the plate boundary ends the growth of the mountain belt, but the suture of collision remains marked by a very lofty mountain range, made up of highly folded and thrust faulted rocks, coincident with or adjacent to the magmatic belt, and by a much thickened continental crust."

As such highly elevated mountains are formed, erosion starts to wear them low. The eroded debris is carried down to oceans and seas as well as to inter-montane valleys so that the rock cycle may be repeated over and over again. As erosion removes large quantities of rock masses, isostatic adjustment gradually raises the mountains in response. Prolonged erosion, coupled

with isostatic adjustments eventually reduce the mountainous chain to the average thickness of the continent, when the deepest roots of the chain are brought up to the shallower depths of the Earth's crust. In this manner, mountains have played a significant role in the evolution of continental crust, as continents are believed to have gradually grown larger by the addition of linear mountainous terrains to their flanks (e.g. the Appalachians of the eastern United States and the Andes of western South America). This hypothesis implies that nearly all continental areas once stood as mountains and were subsequently lowered to their present elevations by erosion, and that the relatively stable, old, cratonic shields at the heart of the continents are nothing but the roots of such old mountains.

(c) How Mountains Act as a Means of Fixation for the Earth's Lithosphere

As summarized above, the lithosphere (which is approximately 70 km thick under oceans and 100 km thick under continents) is broken up into about 12, large, rigid plates by rift systems (Text-Fig. 21). These plates float on the plastic asthenosphere and move freely away from or towards each other, and past one another. At one boundary of each plate, molten rock rises to form strips of new ocean floor, and at the opposite boundary, the plate slides underneath the adjacent plate to be consumed in the underlying mantle at exactly the same rate of sea-floor spreading. An ideal rectangular plate would thus have one edge growing at a mid-oceanic rift, the opposite edge being consumed into the asthenosphere of the overriding plate and the other two edges sliding past the edges of adjoining plates along transform faults. In this way, the lithospheric plates

are constantly shifting around the earth, despite their rigidity, and as they are carrying continents with them, such continents are also constantly drifting away or towards each other. As a plate is forced under another plate and melts, more viscous magmas are intruded, while lighter and more fluid ones are extruded to form island-arcs that eventually grow into continents, and plastered to the margins of nearby continents or squeezed between two colliding continents. Traces of what might have been former island-arcs have been detected along the margins and in the interiors of many of today's continents.

The divergence as well as convergence of lithospheric plates are not confined to ocean basins but are also felt along the margins, as well as within and in between continents. Both the Red Sea and the Gulf of California troughs (which are extensions of oceanic rifts) are currently widening at the rate of 3 cm/year in the former and 6 cm/year in the latter case. On the other hand, the collision of the Indian Plate with the Eurasian Plate resulted in the formation of the Himalayan Chain, with the highest peaks on the surface of Earth.

Earthquakes are common at all plates' boundaries (Text-Figs. 19, 22). Along divergent boundaries, these are shallow seated, but along subduction zones, earthquakes have deep foci (to a depth of 700 km). Seismic events also take place where plates slide past each other along transform faults. Movement along planes does not occur continuously, but in sudden jerks, which release accumulated strain.

Lithospheric plates do not all travel at the same speed. Where the plates are rapidly diverging, the extrusive lava spreads out over a wide region and forms a broad mid-oceanic

ridge, with gradually sloping sides (e.g. the East Pacific Rise). Contrary to this, slow divergence of plates gives time for the erupting lava to accumulate, leading to the formation of steep crests (e.g. the Mid-Atlantic Ridge). It is comparatively simple to determine the rates of movement away from spreading centers by the use of magnetic anomaly strips. These can now be identified and dated, and the distance of an anomaly from its spreading center can be easily measured and hence, the average spreading rate can be calculated.

Spreading rates at mid-oceanic ridges are usually given as half-rates; that is the rate at which one lithosphere plate moves away from the ridge. The full spreading rate is the velocity differential between the two plates which originate at the ridge. Plate velocities at trenches are full rates. In the pattern of motion of plates and plate boundaries, nothing is fixed, all velocities are relative. Spreading rates vary from about 1 cm/year in the Arctic Ocean, to about 18 cm/year in the Ocean, with the average being 4 to 5 cm/year. Apparently, the Pacific Ocean is now spreading almost ten times faster than the Atlantic (cf Dutt and Batten, 1988, p. 167).

Rates of convergence between plates at trenches and orogenic belts can be computed by vector addition of known plate rotations. Le Pichon (1968) assembled a set of such computations, which show whole rates of convergence as high as 9 cm/year at trenches and as low as less than 6 cm/year along mountain belts. Rates of slip along transform faults can also be easily calculated, once the rates of plate rotation are known.

The patterns of magnetic anomaly strips and sediment thicknesses suggest that spreading patterns and velocities have

been different in the past, and that activity along mid-oceanic ridges varies in both time and space and consequently ridges appear, migrate, and disappear. Spreading from the mid-Atlantic ridge apparently began between 200 and 150 M.Y.B.P., from the Northwestern Indian Ocean ridge between 100 and 80 M.Y.B.P., and Australia and Antarctica did not separate until 65 million years ago. (cf Dott and Batten, loc. cit.)

Volcanoes are also abundant at divergent boundaries, whether under sea or on land. Most of these volcanoes have been active for a period of 20-30 million years although some have persisted in their activity for 100 million years or even more (e.g. the Canary Islands). During such long periods of activity, volcanoes have been carried away for several hundred kilometers from the constantly renewed plate edge, and presumably out of reach of the magma body that fed them, and hence fade out and die. The floor of the Pacific Ocean contains a great number of submerged ancient volcanoes (guyots) that once were above the ocean surface, but later sank below it as the underlying lithosphere moved away from the zone of spreading and subsided.

Continental orogenic belts are the result of plate boundary interaction, and such interaction reaches its climax when two continents come into collision. This results in considerable crumpling of the margins of the two continents and the cessation of all forms of activity at that junction. The two lithospheric plates become welded together, with considerable crustal shortening in the form of giant thrusts and infrastructural nappes, as well as considerable crustal thickening in the form of deep roots that extend downwardly for several times the

elevation of the mountainous chain. Consequently, these collosal chains with their very deep roots stabilize the Earth's lithosphere as plate motions are almost completely halted at their place. Again, the notion of a plastic asthenosphere makes it possible to understand why the continents are elevated above the oceanic basins, and why the crust beneath them is much thicker than it is beneath the oceans. This implies that inasmuch as mountains have very deep roots, all elevated regions such as plateaus and continents must have corresponding roots extending for an exceptional distance downward in the asthenosphere. In other words, the entire lithosphere is floating above the plastic or semi-plastic asthenosphere, and its elevated structures are only held steadily by their downwardly plunging roots (Text-Fig. 1).

Lithospheric plates move about in response to the way in which heat arrives at the base of the lithosphere (Text-Fig. 23), and perhaps also because of the rotation of the Earth about its own axis. Both processes are believed to have been more active in the geologic past, and hence it has been predicted that plate movement operated more rapidly before and has been slowing down due to the steady building of mountainous chains and accretion of continents. This may also be aided by a steady slowing down in the Earth's rotation, which would be attributed to the gravitational pull of both the sun and the moon, and also to the lesser amount of heat arriving from the interior of the Earth to its surface as a result of the continued decay of radioactive material.

CONCLUSION

Mountains have always been looked upon as conspicuous landforms, characterized by lofty protrusions above their surroundings, high peaks and steep sides, as well as by their presence in complex ranges that run more or less parallel to each other or in single prominences.

Nevertheless, the Qur'an consistently describes mountains as stabilizers for the Earth, that hold its outer surface firmly lest it should shake with us, and as pickets (or pegs) which hold that surface downwardly as a means of fixation. So, simply stated, the Qur'an describes the outward protrusion of mountains from the Earth's surface, and emphasizes their downward extensions within the Earth's lithosphere, as well as their exact role as stabilizers and as a means of fixation for such a lithosphere.

These facts started to come to light only in the middle of the nineteenth century (almost 13 centuries after the revelation of the Qur'an), when George Airy (1865) (in an attempt to explain reduced deflections in plumb-bobs near mountain masses than the calculated values of gravitational attraction) came to realize that the excess mass of the mountains above sea level is compensated by a deficiency of mass in the form of underlying roots which provide the buoyant support for the mountains. Airy (op. cit.) proposed that the enormously heavy mountains are not supported by a strong rigid crust below, but that they "float" in a

"sea" of dense rocks. In such a plastic, non-rigid "sear' of dense rocks, high mountains are buoyed up at depth in more or less the same way an iceberg is hydrostatically buoyed up by water displaced by the great mass of ice below the water surface. A mountain range is isostatic in relation to surrounding portions of the Earth's crust. That is, mountains are merely the tops of great masses of rocks, floating in a more dense substratum as icebergs float in water. A mountain with an average specific gravity of 2.7 (that of granite) can sink into a layer of plastic simatic rock (with a specific gravity of 3.0) until the range is floating with a "root" of about nine-tenths, and a protrusion of one-tenth its total volume. In some cases, the ratio of the mountain's "root" to its elevation can go up to 15:1, depending on its rock composition and the average density of the material in which its root is immer sed.

Such observations have led to the concept of isostasy (Dutton, 1889) and have introduced the principles of gravity surveying. Again, both seismic and gravitational evidences have indicated that the crust is thickest under mountains and is thinnest under oceanic basins. These facts could not be clearly understood until the early 1960s when the development of the theory of plate tectonics had started to proceed apace. In this theory of global tectonics, the lithosphere is split by major zones of fractures into a number of slabs or plates (about 100 km thick) that float on a denser, more plastic substratum (the asthenosphere), and hence glide above it and move across the surface, being aided by the rotation of the earth about its own axis. The boundaries of such lithospheric plates are outlined by the locations of both earthquakes and intensive volcanicity. Such plates are accreted at their divergent boundaries (midoceanic

ridges) by rising molten rocks that form new ocean floor, and are consumed by returning to the Earth's interior and melting at their convergent boundaries. At other boundaries, the plates are simply sliding past each other along transform faults. In this manner, the plates shift around the Earth, despite their rigidity, and carry the continents with them, resulting in the phenomenon of continental drift.

As the lithospheric plates move horizontally across the Earth's surface, they collide from time to time, producing high mountain ranges. The product is determined by the composition of the plates at the point of collision, but in all cases, oceanic and continental mountains are formed (island-arcs, volcanic mountains, cordilleran chains and collisional mountains).

As a plate is forced under another plate and melts, the lighter magma rises to form island-arcs that eventually grow into continents. All continents are believed to have their origins in processes of this kind, and further collision of continent/island-arcs or continent/continent can lead to the further growth of continents and to the stability of the Earth's crust. From seismic evidence, it is clear that the continental crust is 6-8 times thicker than the oceanic crust (30-40 km versus 5 km) and is slightly less dense (2.7 versus 2.9).

The lithospheric plates do not all travel at the same speed, and are believed, in general, to be slowing down with time. The details of how the motion occurs are still in doubt, but two hypotheses have been put forward: convection spreading and gravity spreading, the former of which seems to be gaining more support. Plates probably move about in response to the way in which heat arrives at the base of the lithosphere, and this was

apparently much faster in the geologic past, because of the greater quantities of radioactive decay, the excessive heat generated by the solidification and growth of the earth's inner core, and the faster rate of rotation of the Earth.

The role of mountains as stabilizers for the Earth's crust can be clearly seen in their very deep roots, and can be justified by the fact that the motions of the lithospheric plates only come to halt when a continent collides with another, producing a collisional type mountain, which is believed to be the last phase in mountain-building. Without mountains, the movement of lithospheric plates would have been much faster and their collision more drastic. Even though mountains do act as retarders for the plate movements, they should not be understood to be an independent force or factor, because they are the very product of this motion in the first place.

Again, through the cycle of mountain-building, the Earth's crust is periodically rejuvenated and continents are gradually accreted. New mineral wealth is added and new material for weathering is provided. The more the mountain chain is weathered and eroded, the more it will be isostatically elevated until erosion finally wins the battle over the mountain range when there is no longer enough root to uplift the range by isostasy. The crust beneath the eroded-down, old mountain range will then have the same thickness as the remainder of the continental interior, which is a more or less equilibrium thickness. At this point, the old mountain system becomes a part of the stable craton, the size of the continent is increased, it starts to drift and a new mountain chain or chains start to form at its converging boundary or boundaries.

Such human knowledge about mountains began to accumulate slowly from the mid-nineteenth century, and was not visualized in anything near the above-mentioned framework until the early 1960s, when the theory of plate tectonics was in the process of being formulated.

On the other hand, the Qur'an which was revealed 14 centuries ago as the Book of Divine Guidance has explicitly described mountains as pickets (or pegs) in 22 different verses (out of the 49 where mountains are mentioned or implied). Such pickets were said to fix the Earth's surface down and stabilize it, lest it should shake with us.

Similarly, the Prophet Muhammad (PBUH) who lived between·570 and 632 A.C. is quoted to have said, "*When Allah created the Earth, it started to shake and jerk, then Allah stabilized it by the mountains.*"

Again, the Qur'anic description of the mountains as "pickets" (or pegs) is taken to imply that most of the mountain mass is hidden below the Earth's surface as most of the picket is hidden in either soil or rock to hold the tent to the ground surface.

These are only a few of numerous testimonies for the divine nature of the Qur'an and the messengerhood of Prophet Muhammad (PBUH), as no man knew anything about such facts before the mid-nineteenth century, and that the present-day picture was indeed far from being complete before the 1960s.

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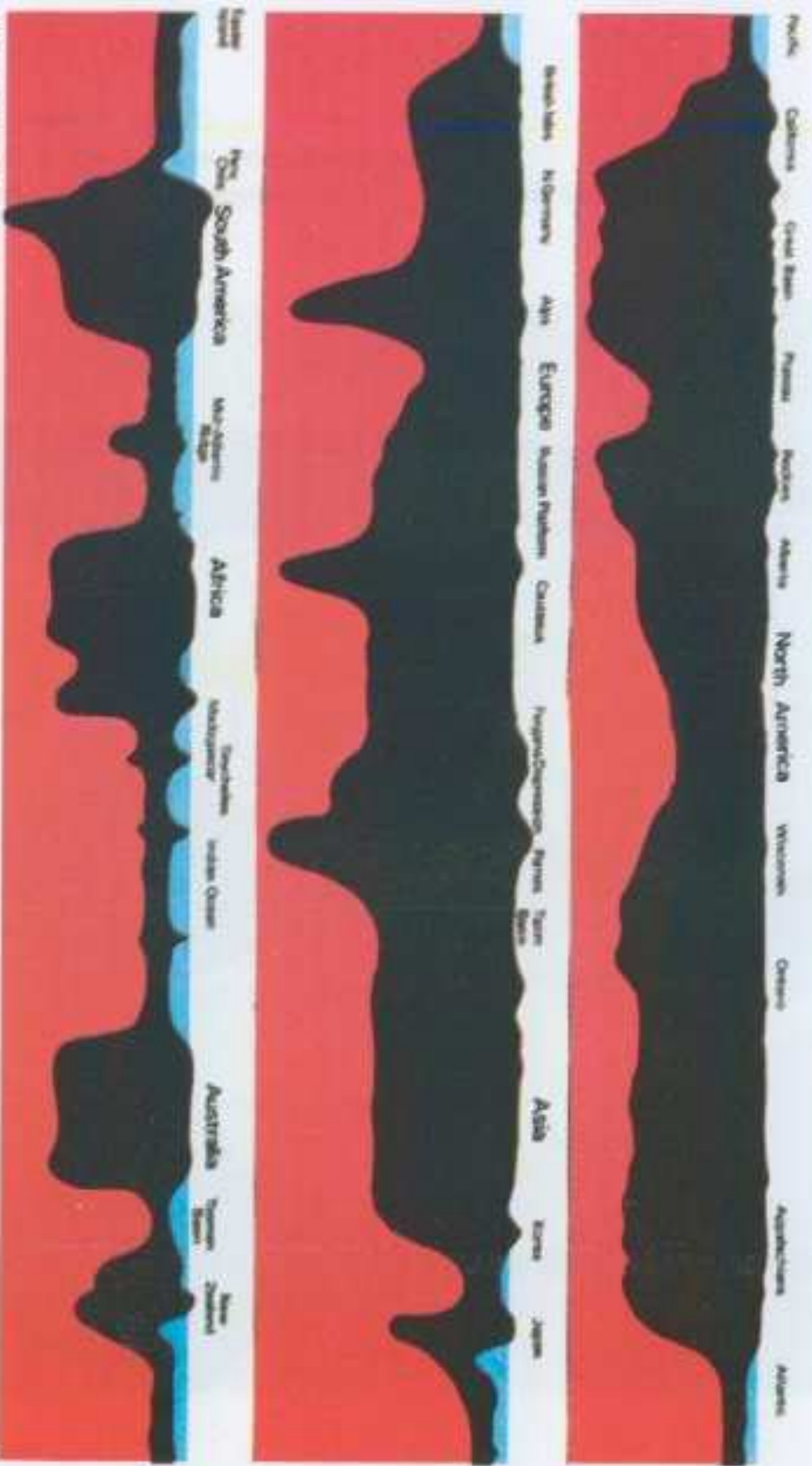
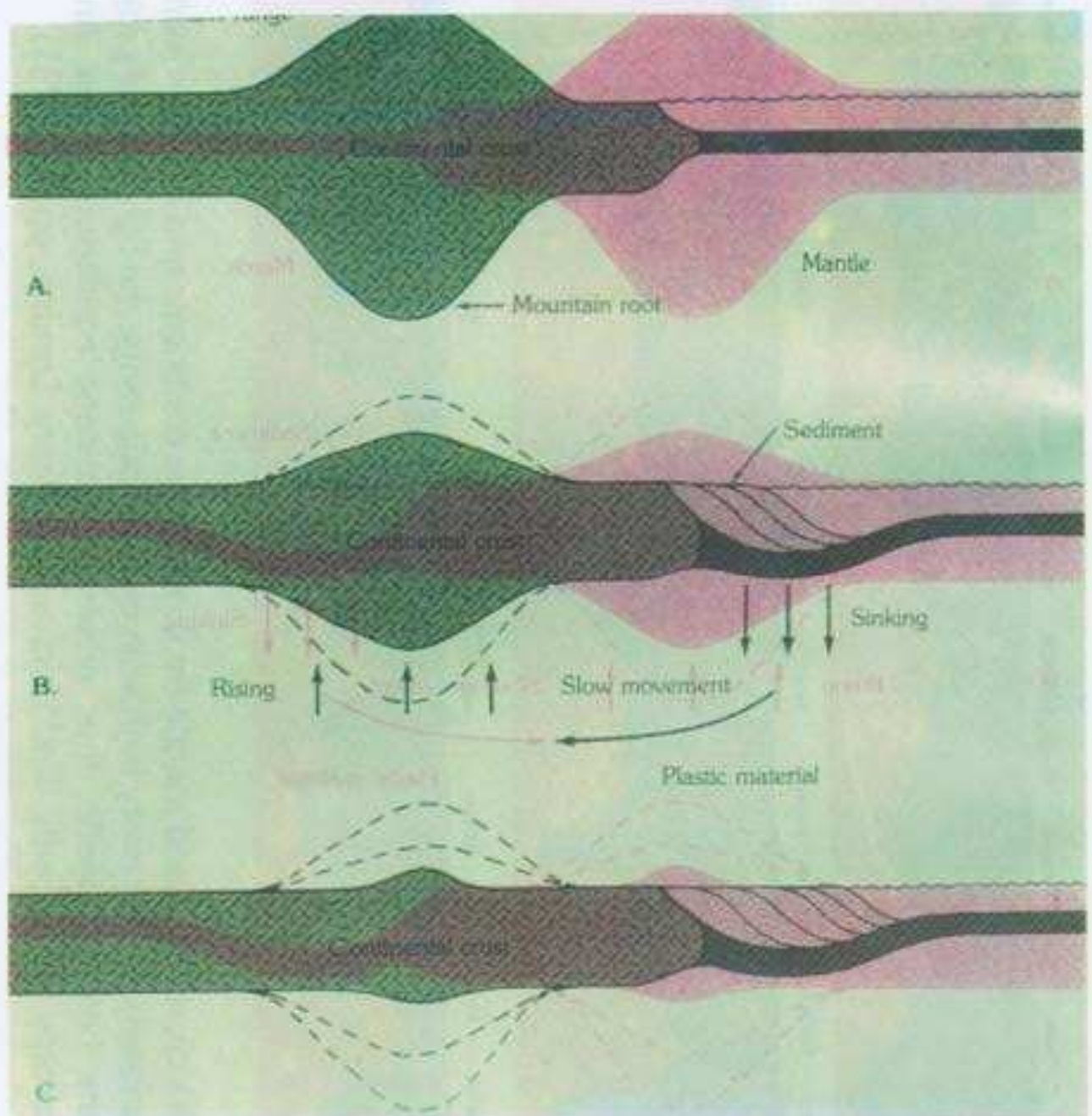
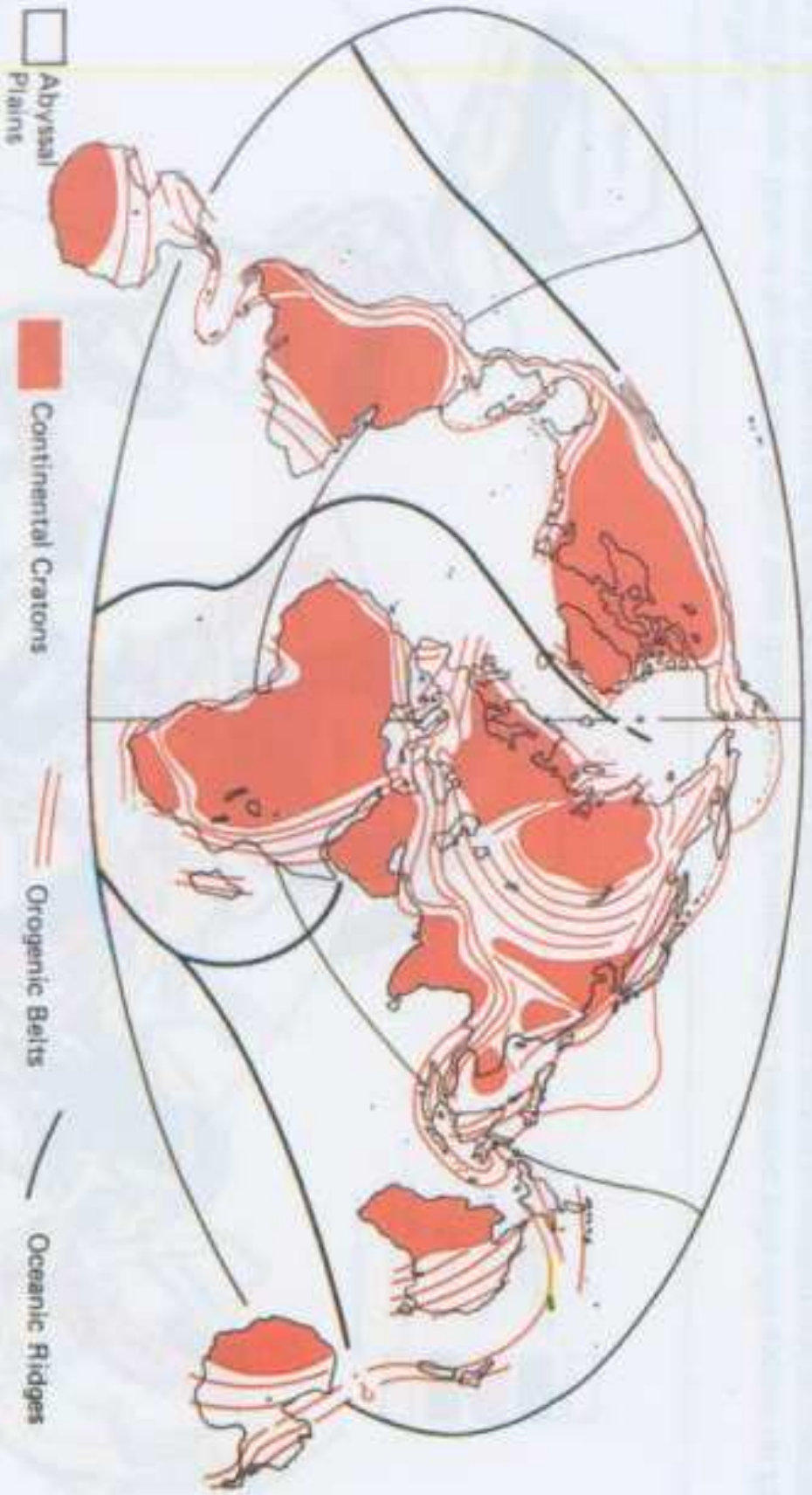
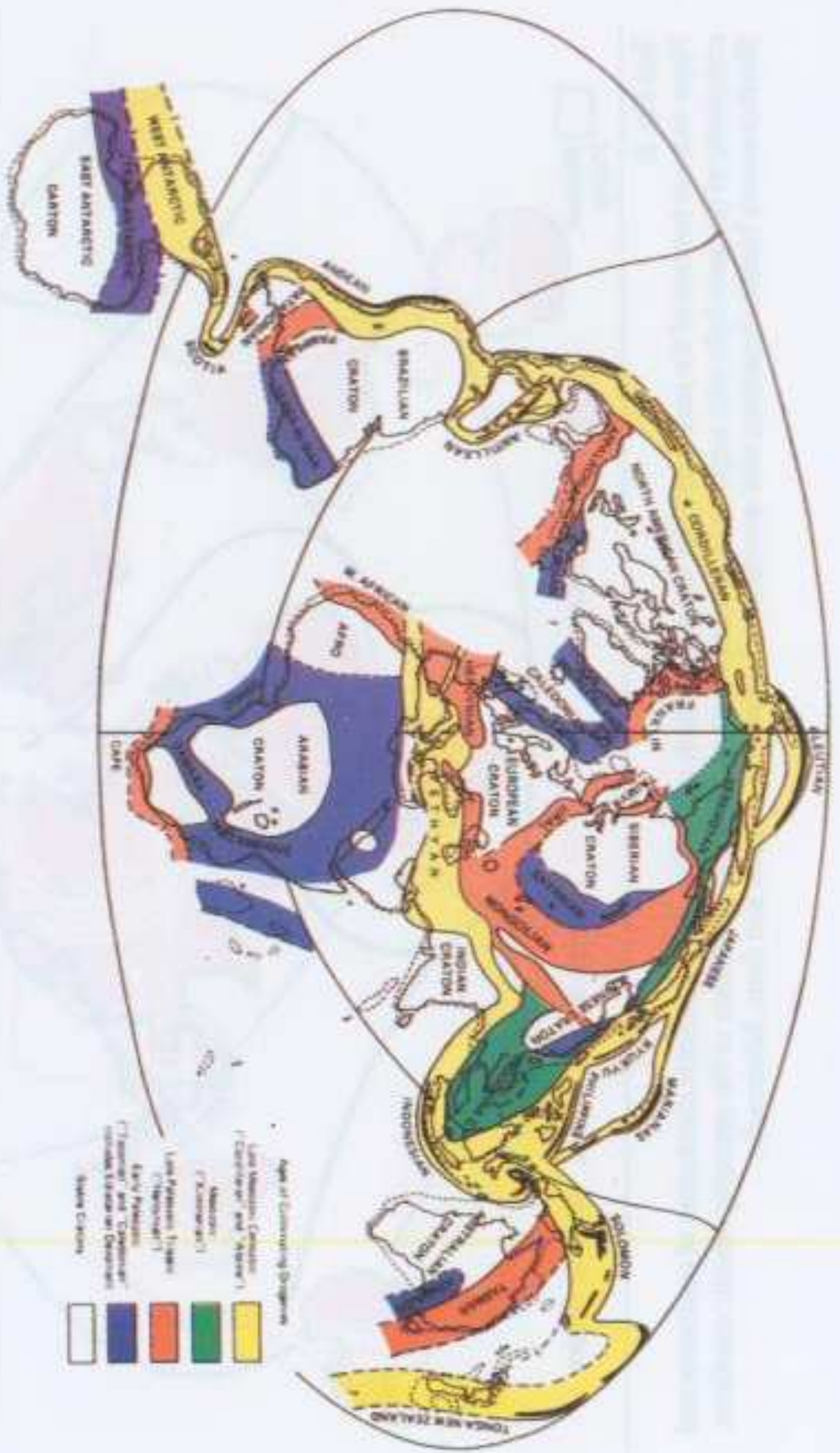
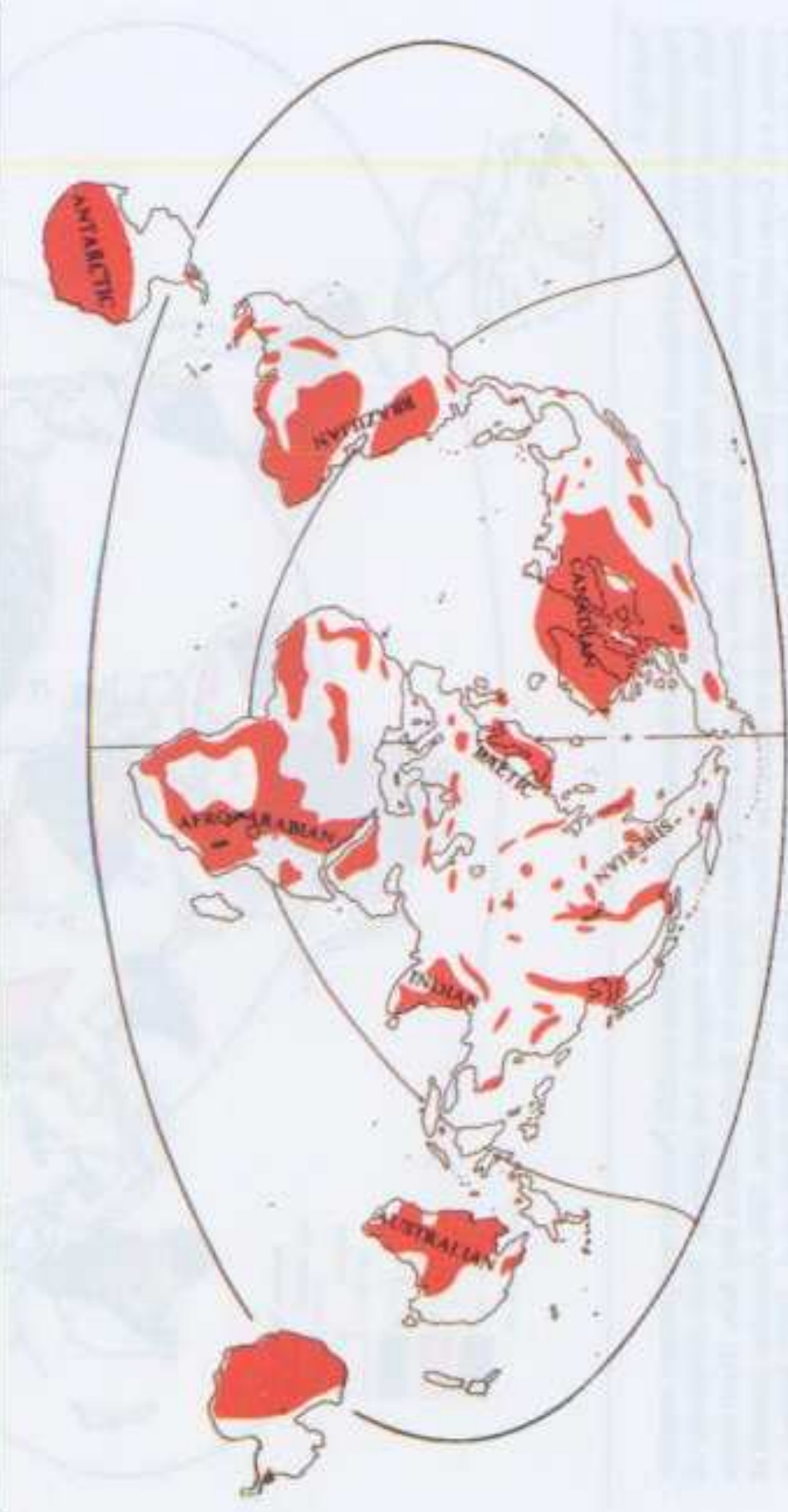
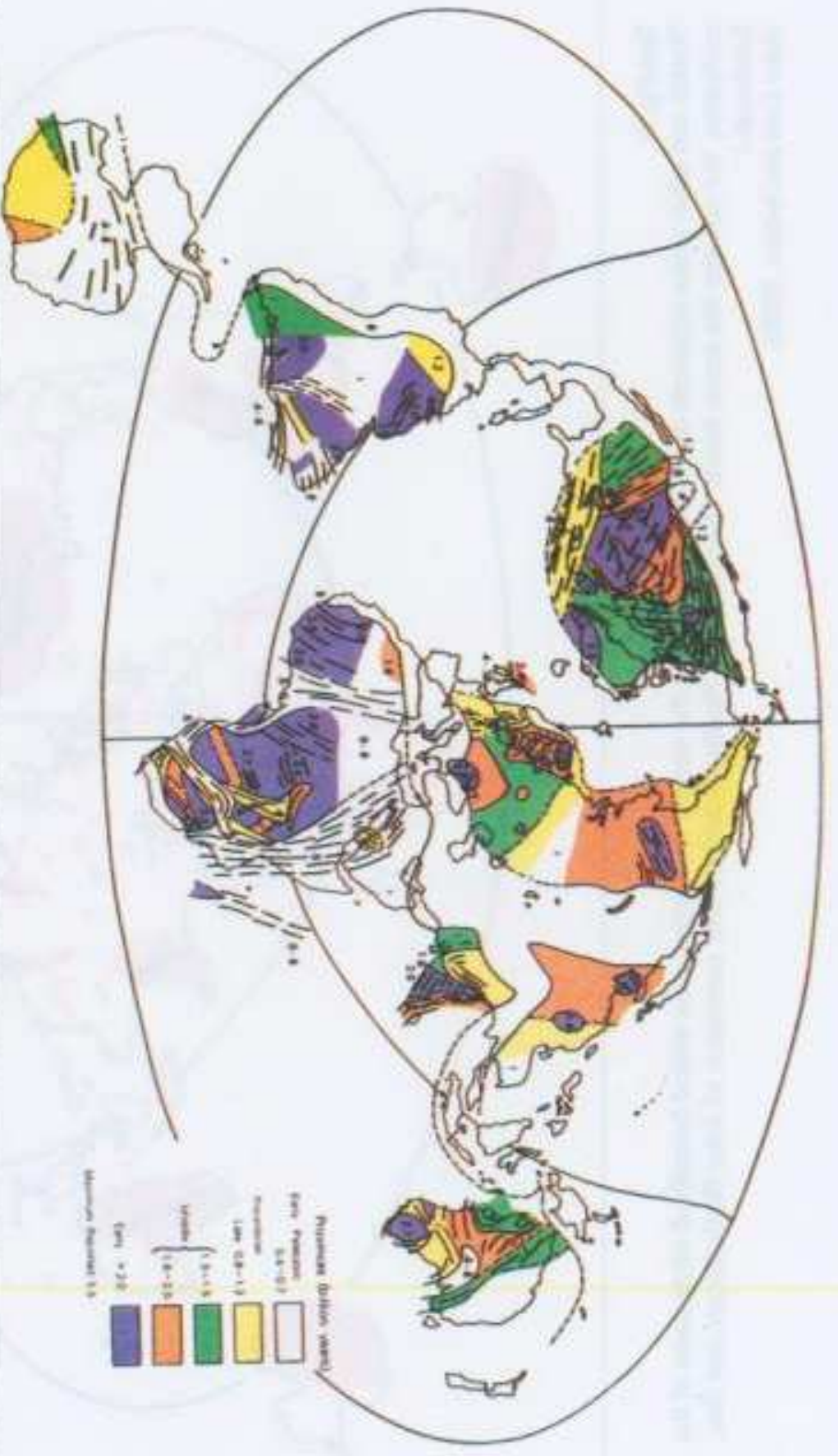
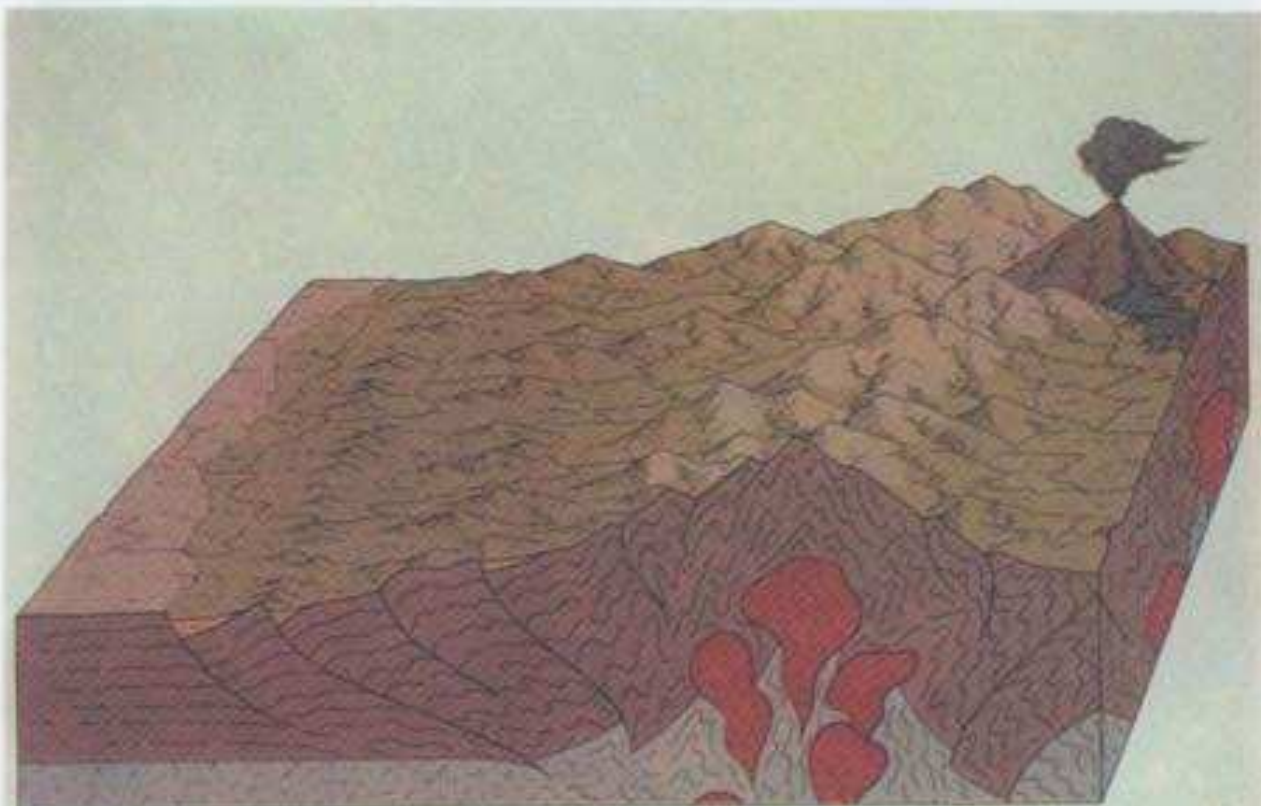
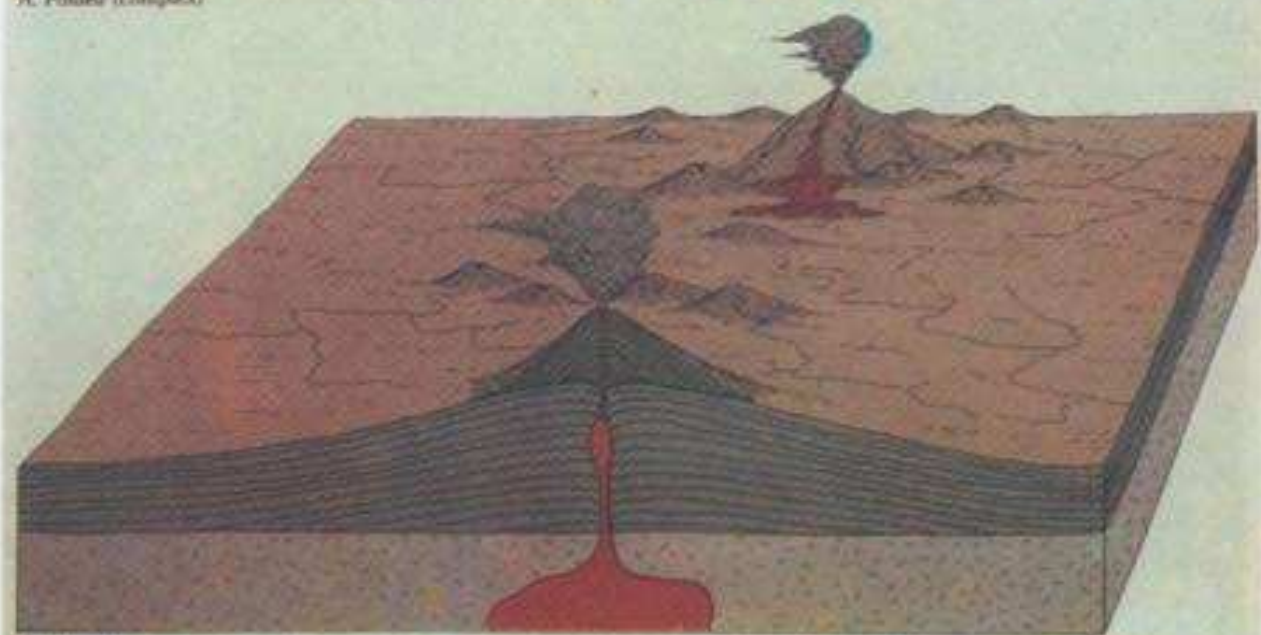
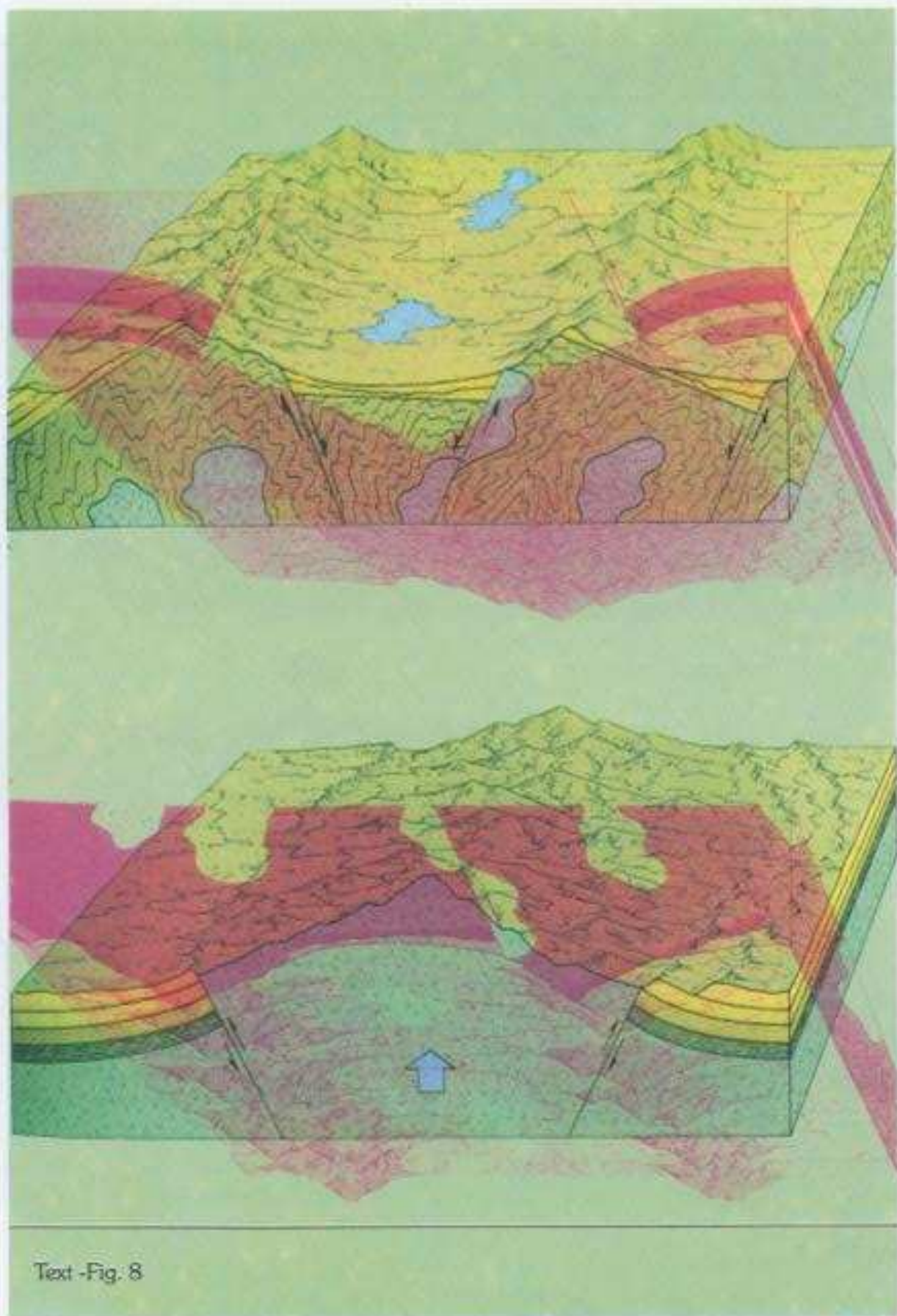
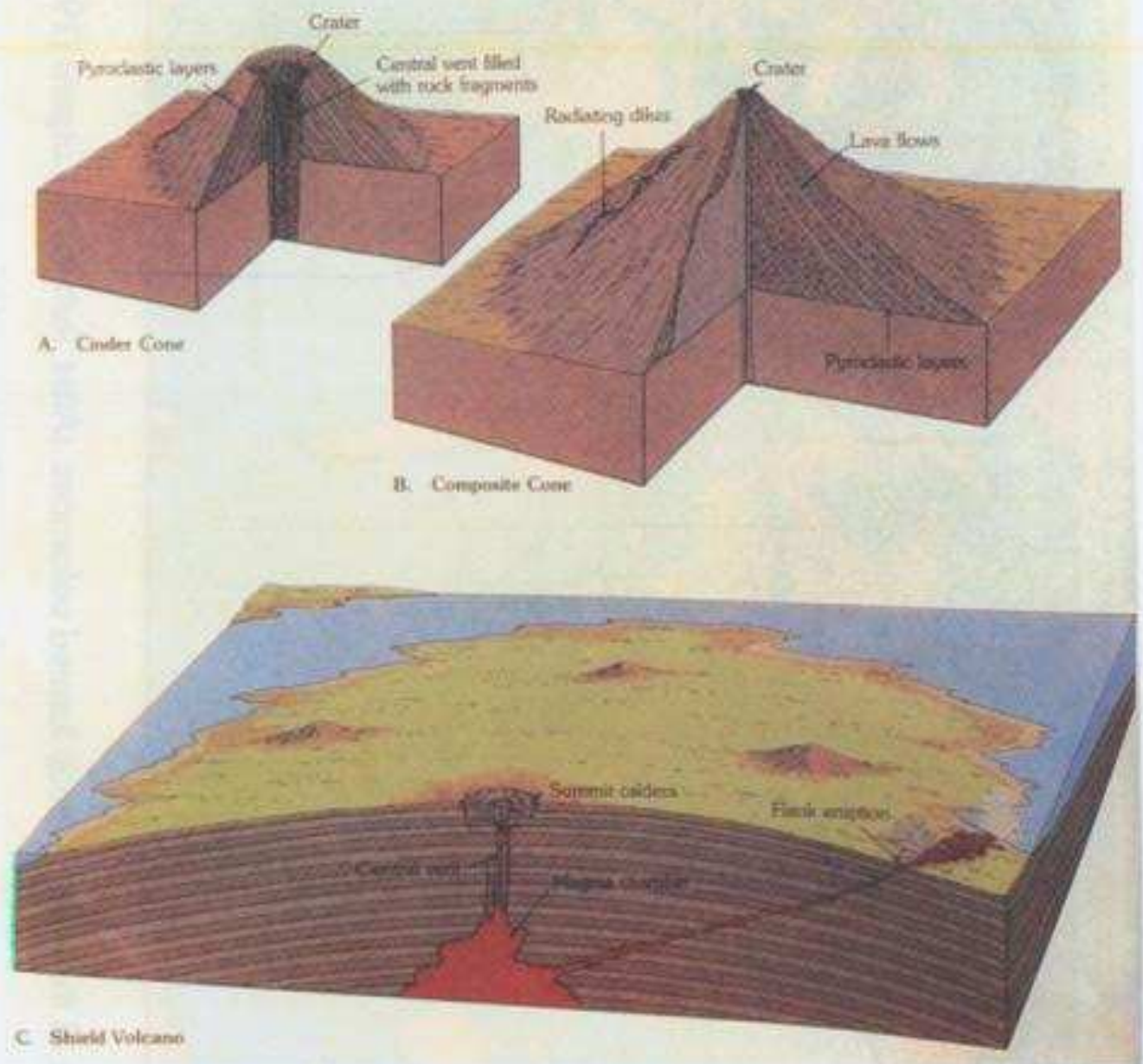
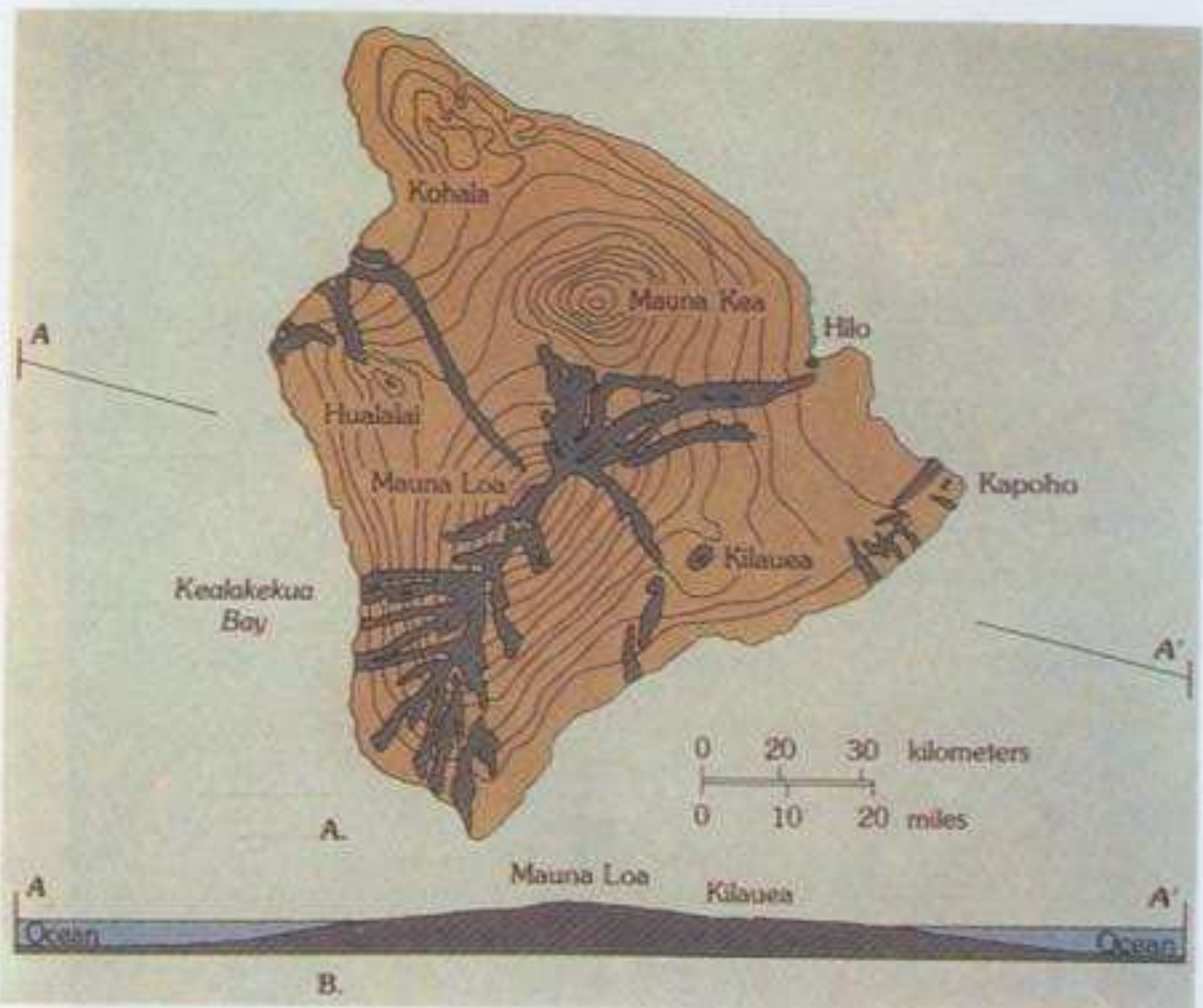
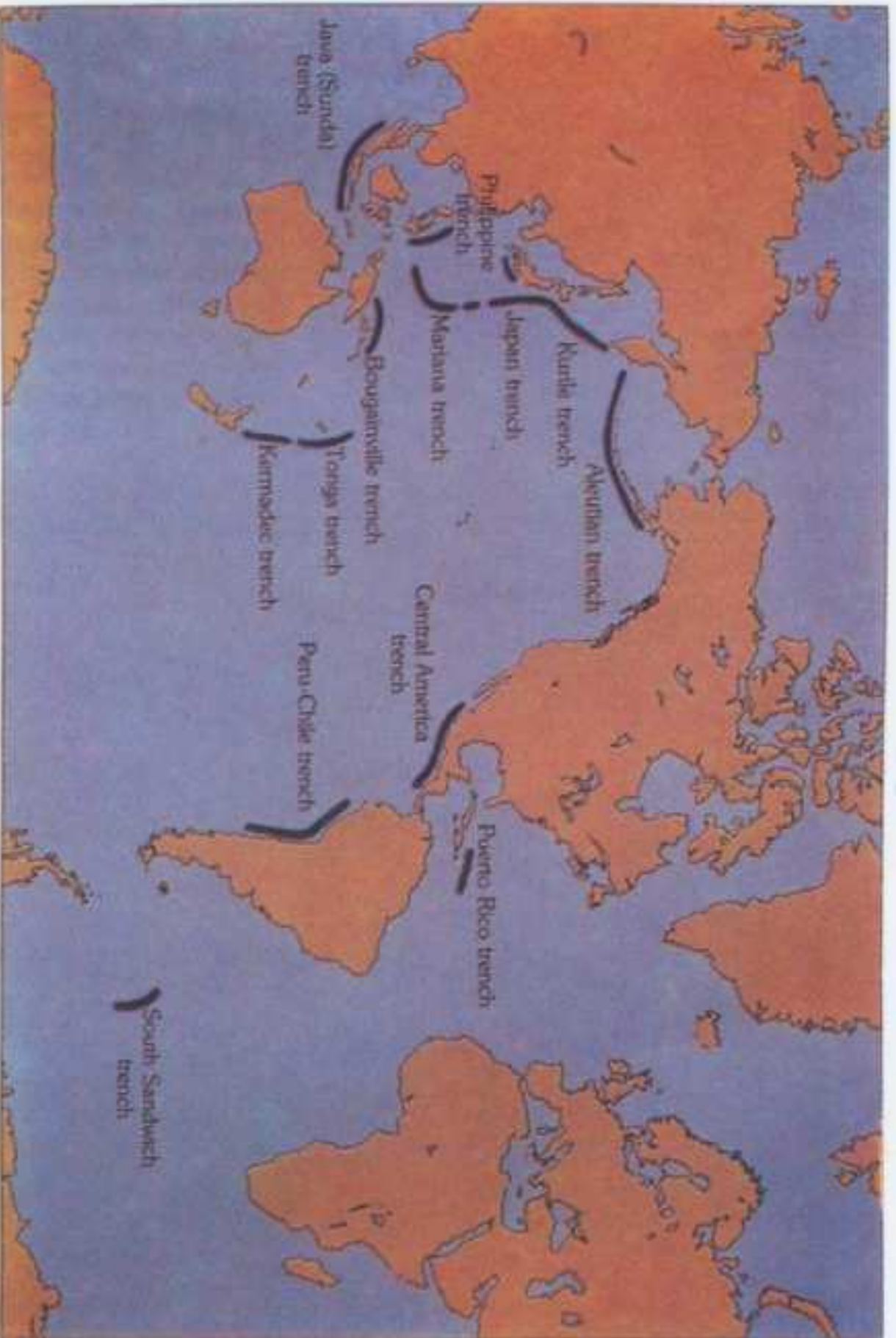
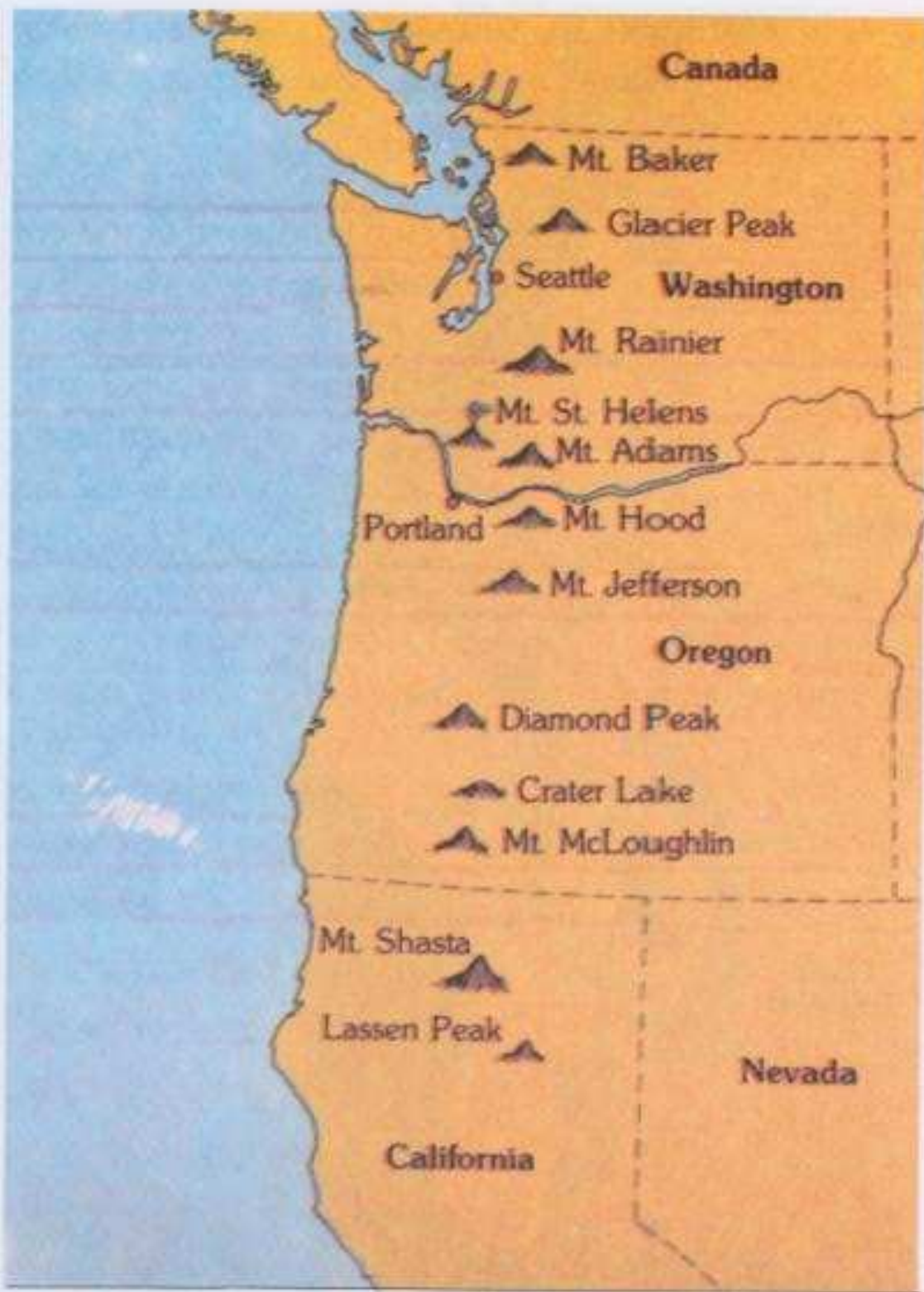
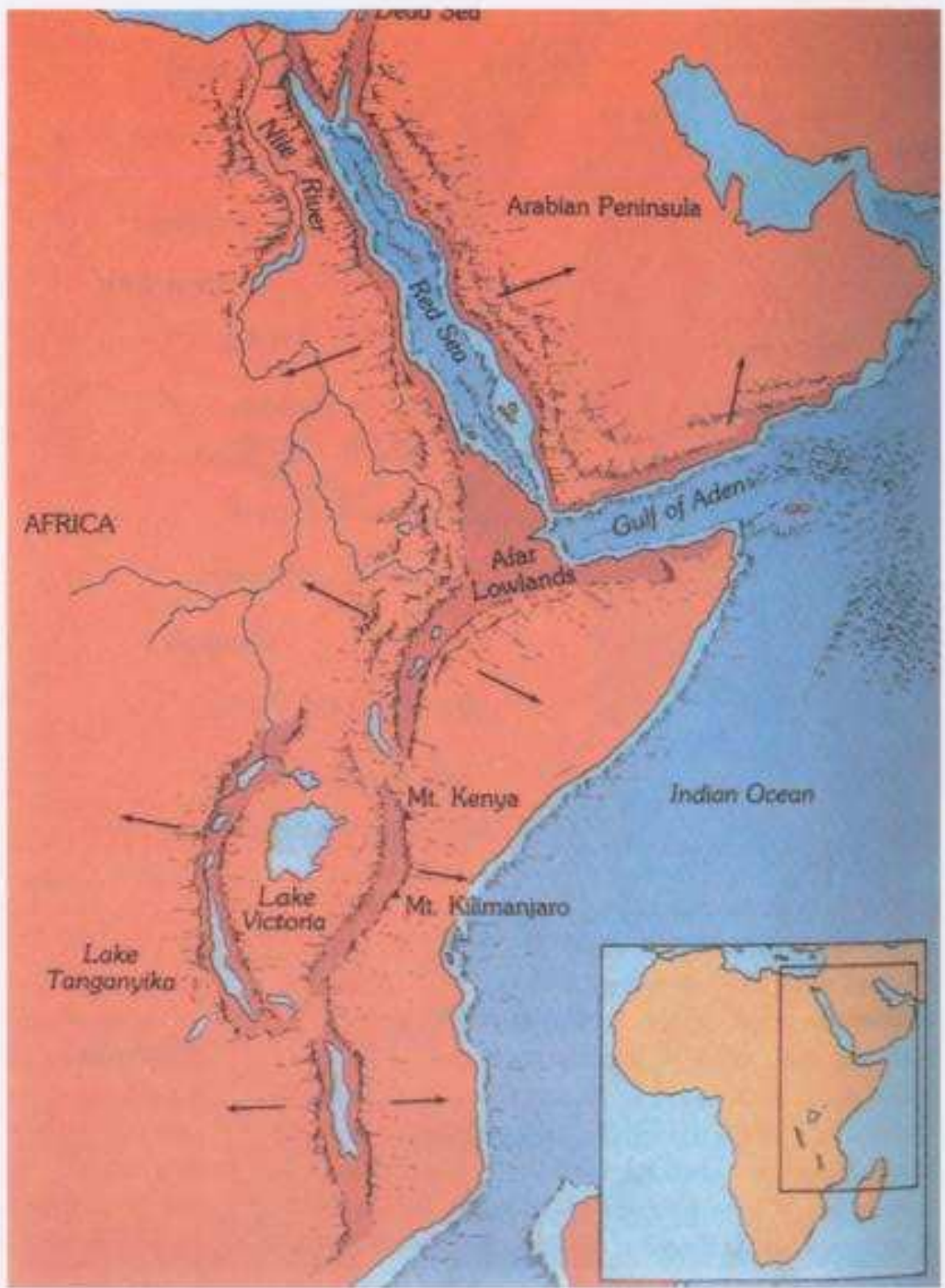
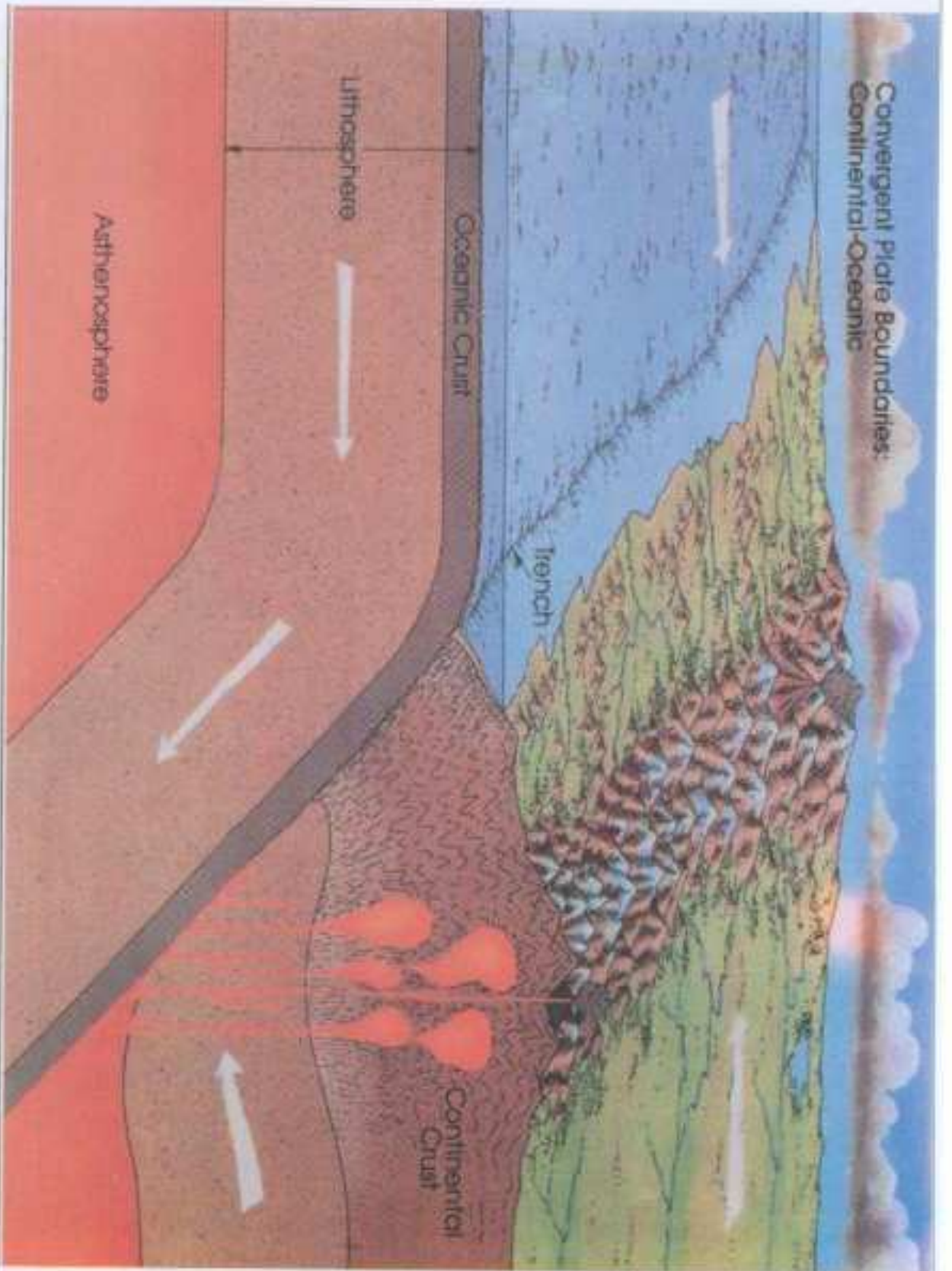
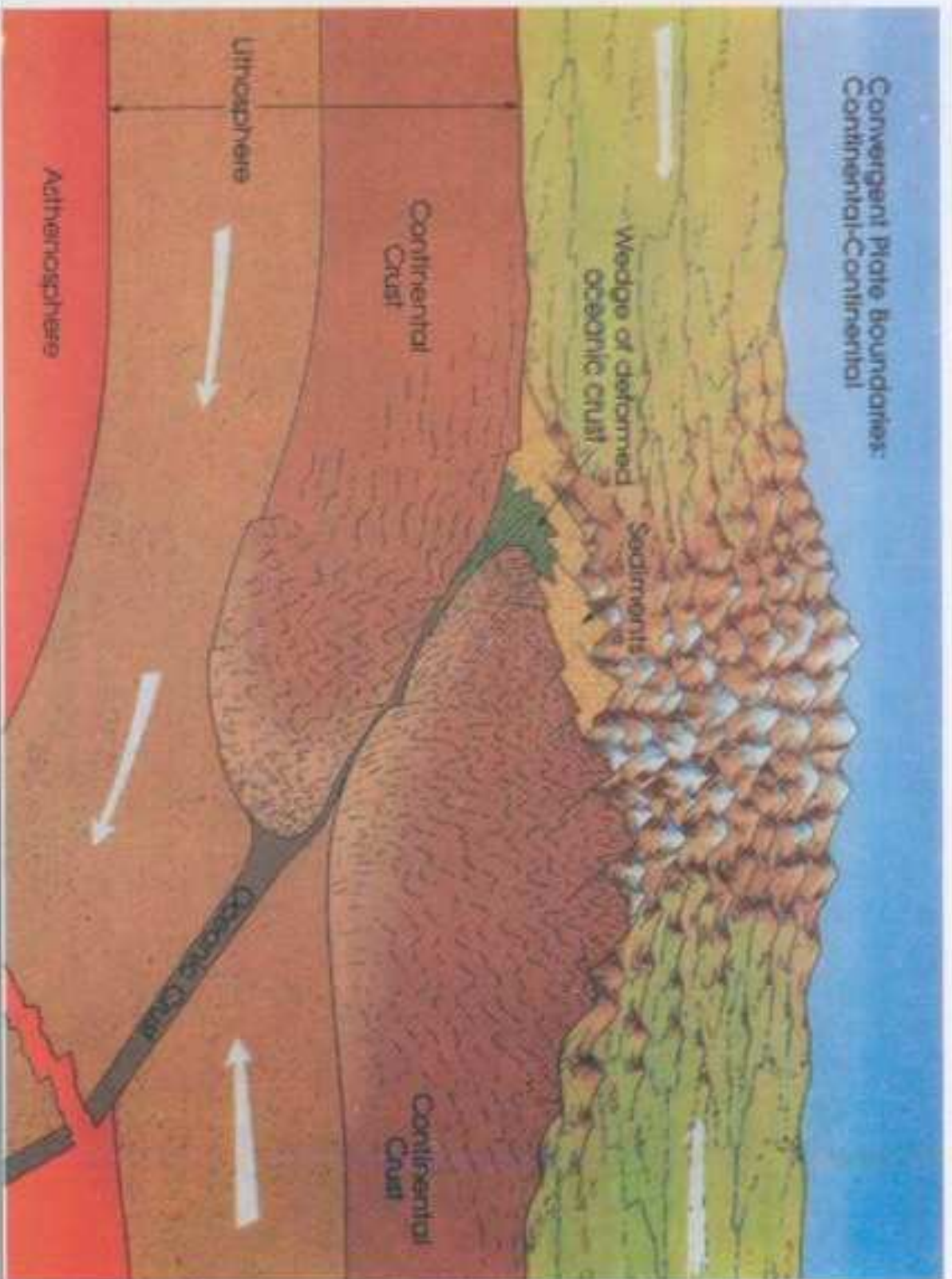
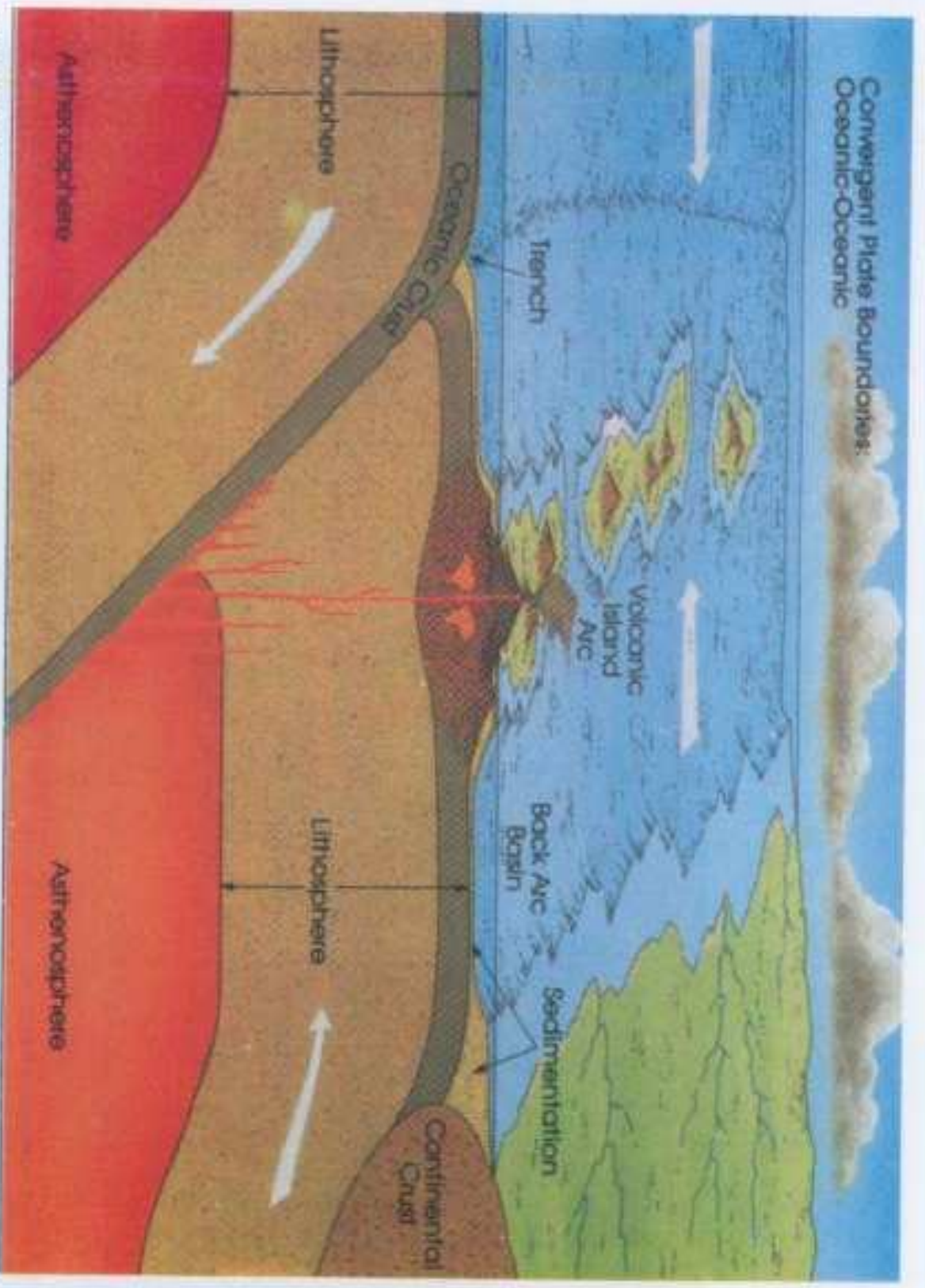
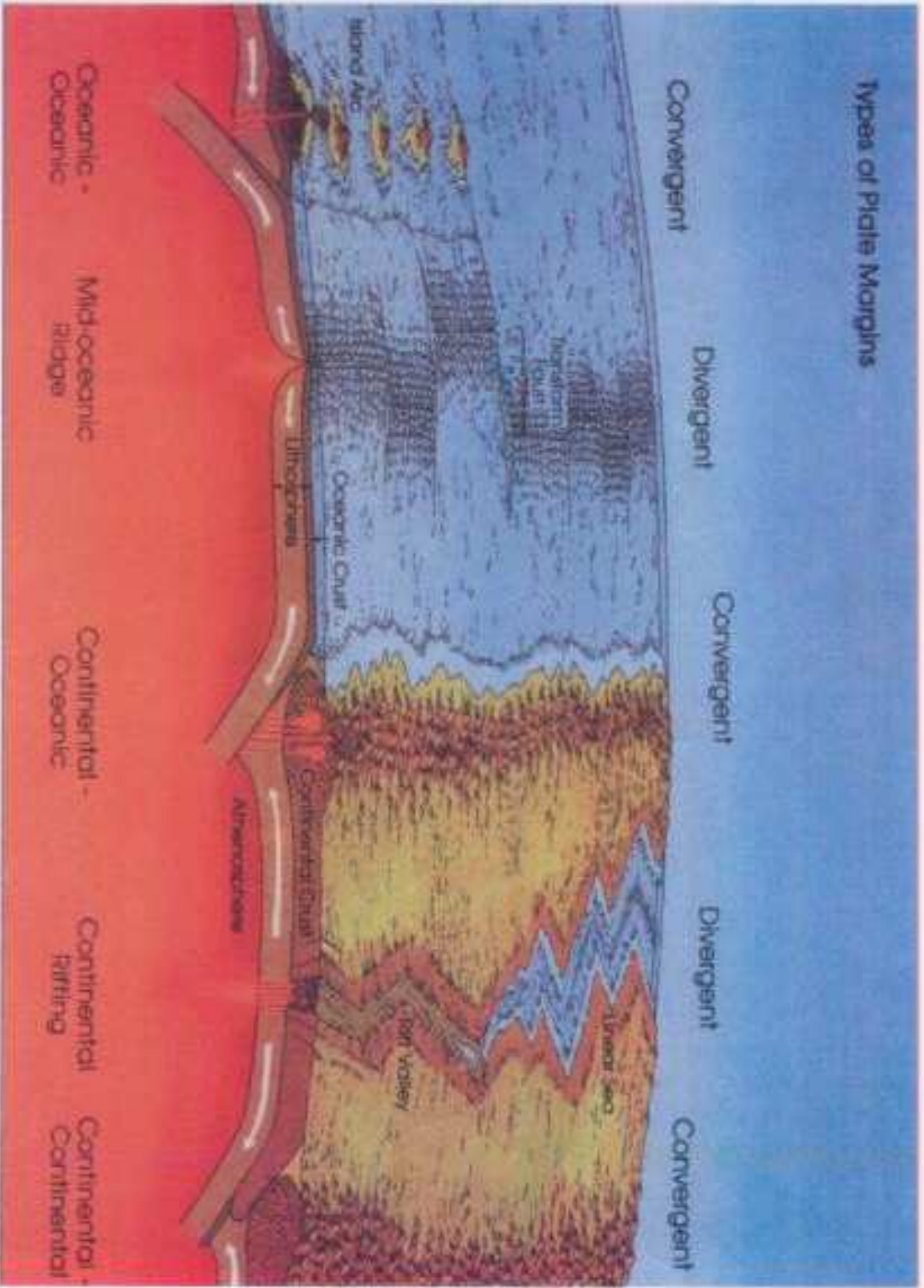
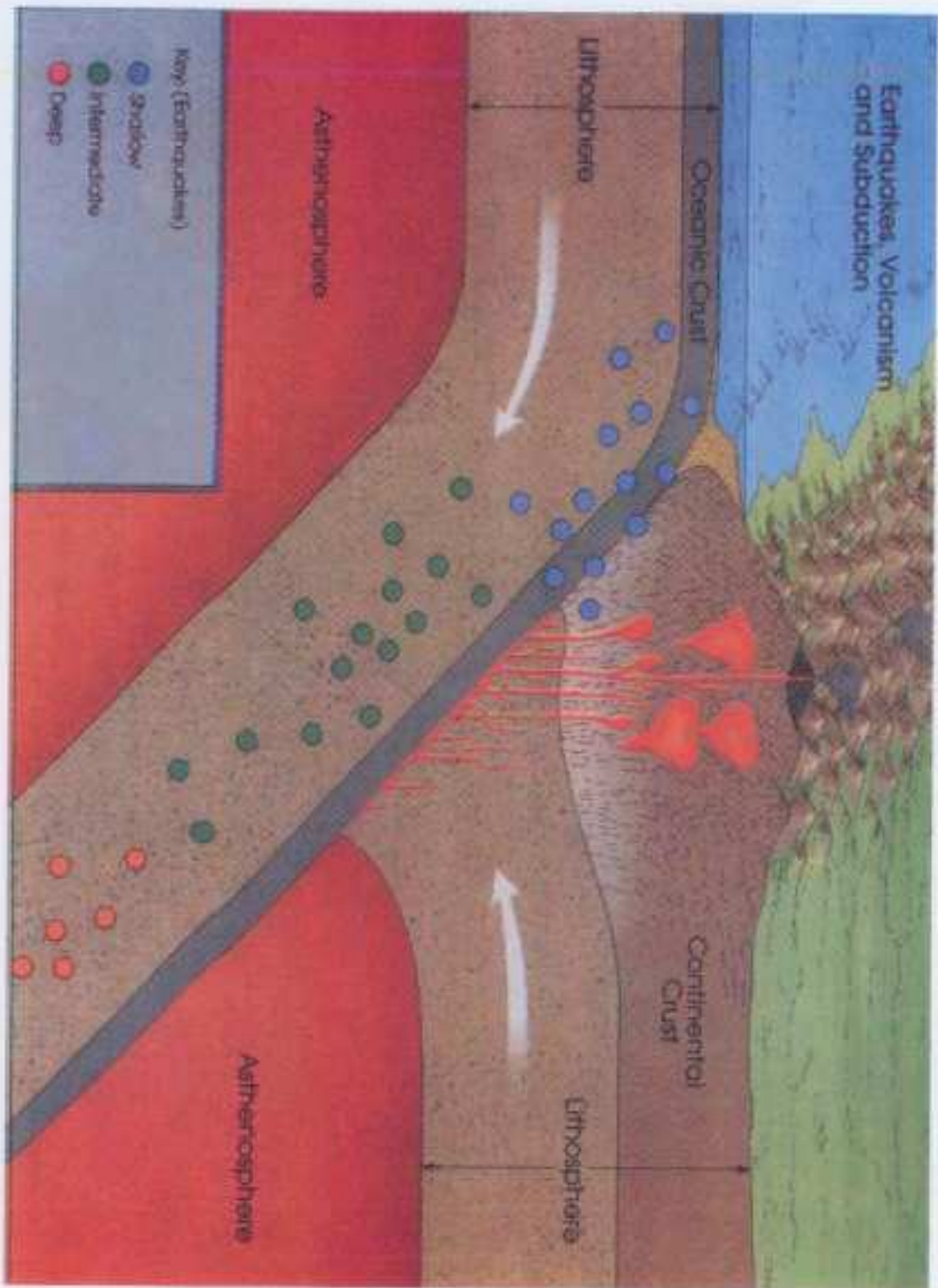
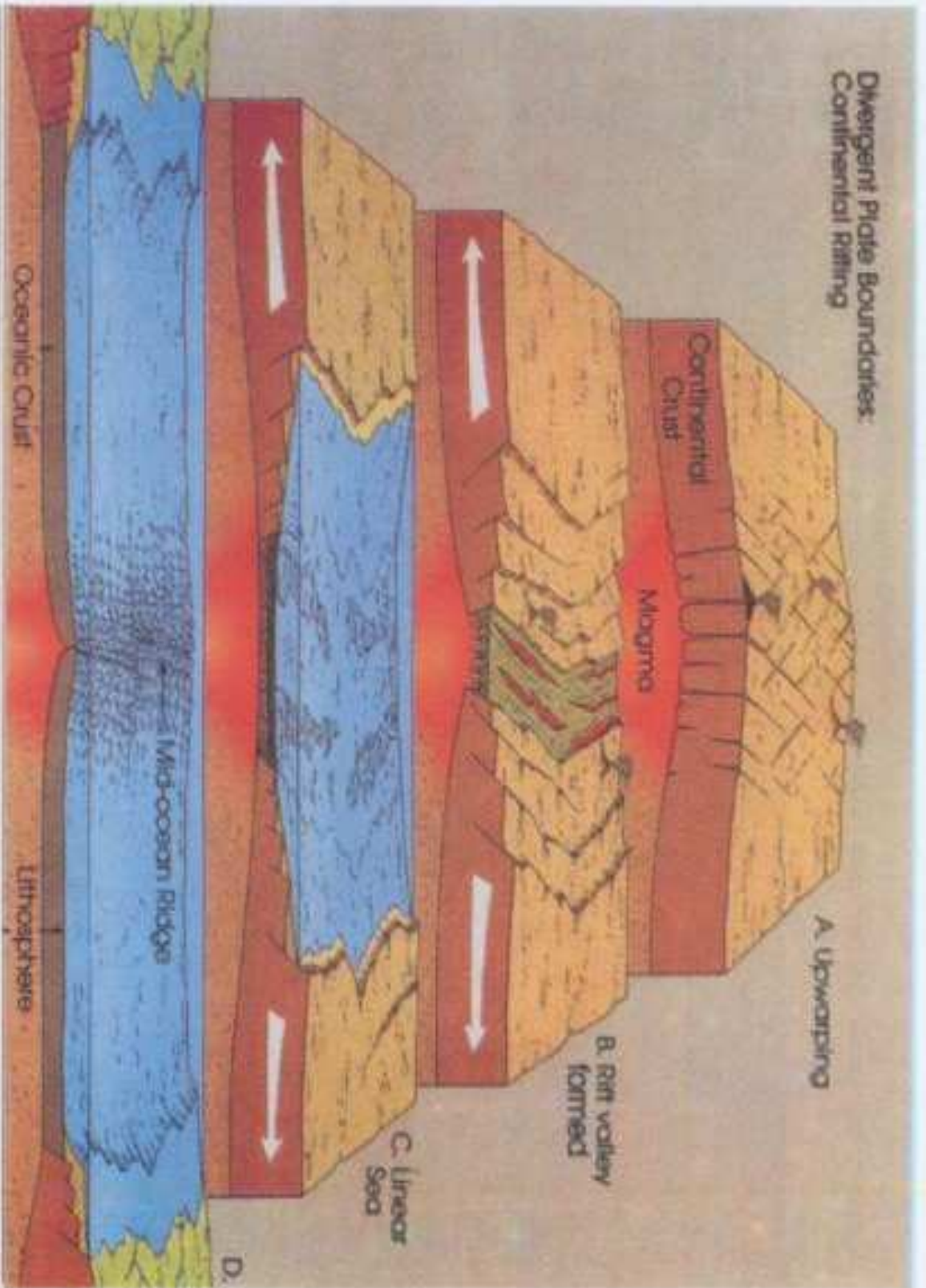
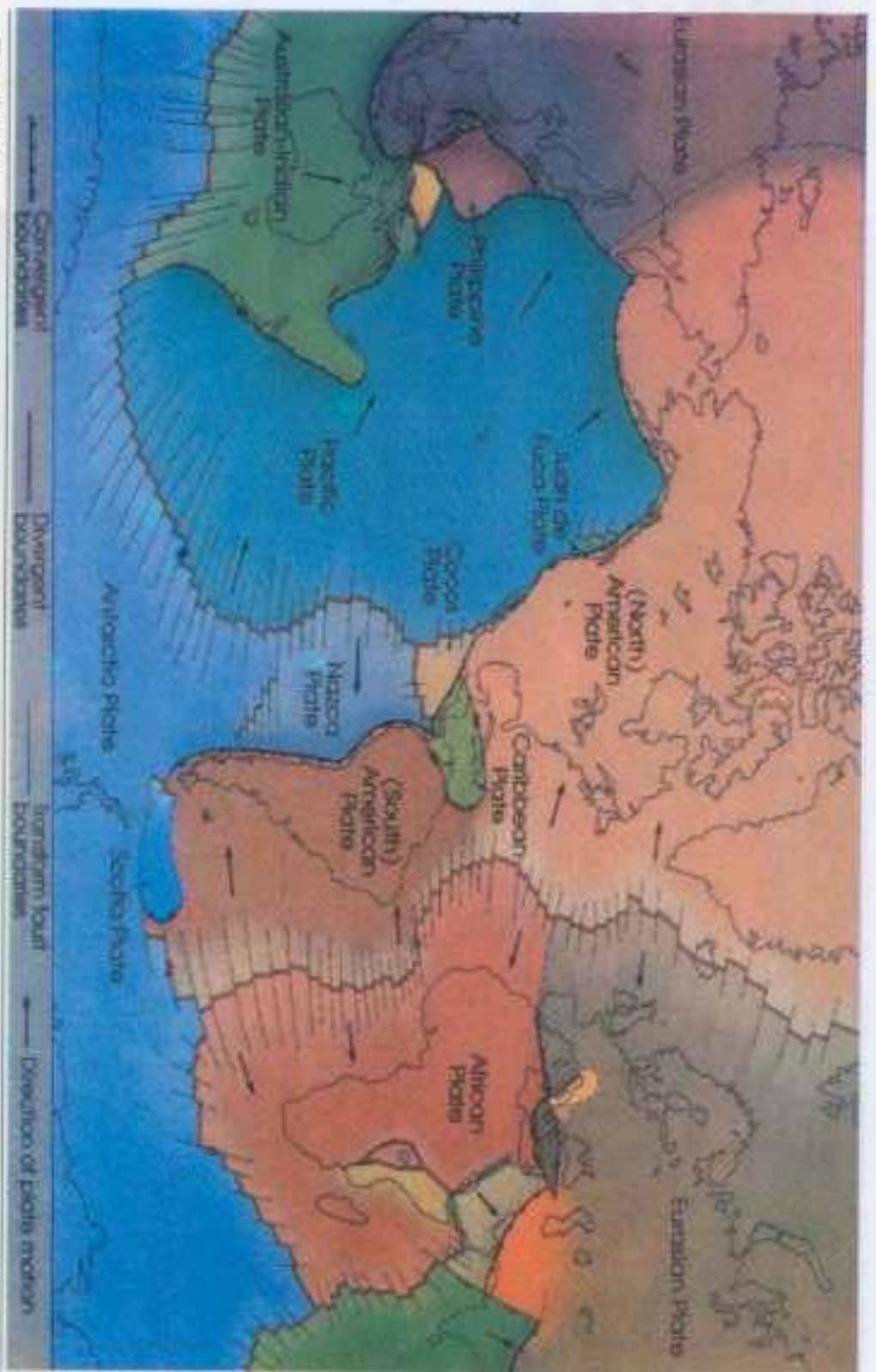
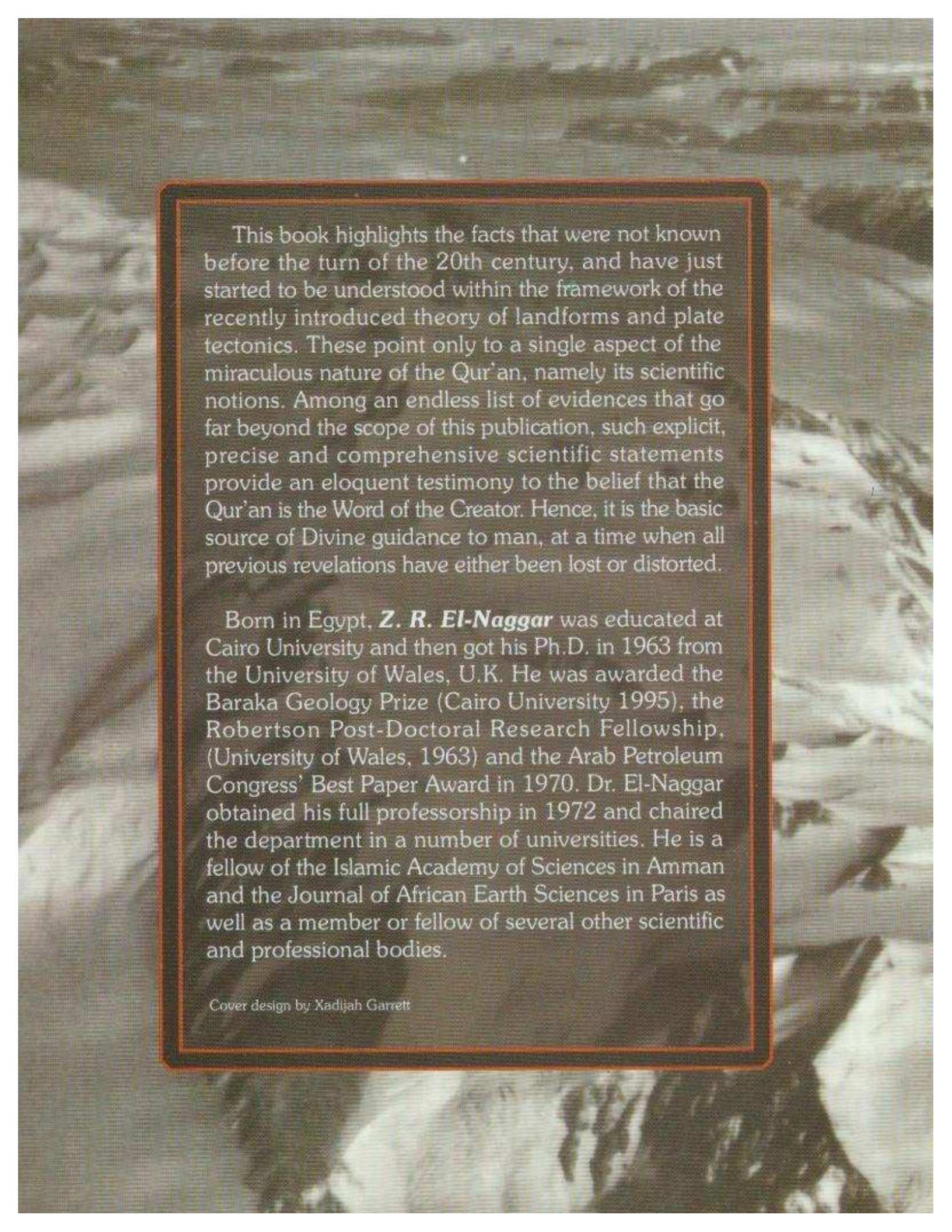
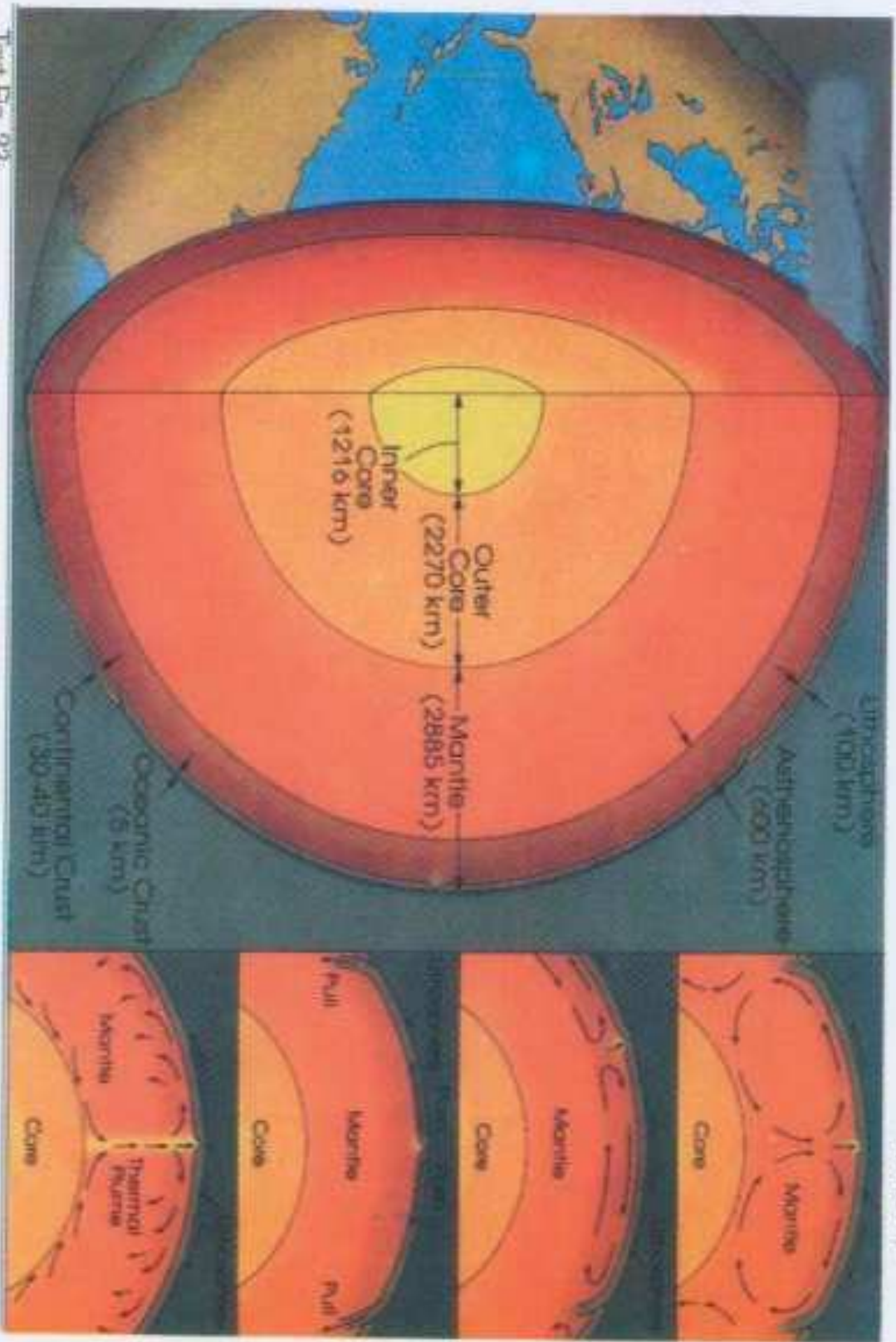
ILLUSTRATIONS

Text-Fig. 1:
Profiles of the earth's crust (grey) and mantle (red) across the continents and oceans (vertical scale greatly exaggerated). Under every high area or mountain range the lighter crust projects downwards into the heavier mantle, thus preserving isostatic equilbrium. (After Andre' Cailleux, 1968: Anatomy of the Earth; World University Library, London, pp. 220, 221).

Text-Fig. 2:
This sequence illustrates how the combined effect of erosion and isostatic adjustment results in a thinning of the crust in mountamous regions.
(After Tarbuck & Lurgens, 1990).

Text-Fig. 3:
Major tectonic features of the earth's crust for the past 1 billion years. Note the asymmetric distribution of continents and complexity of orogenic belts with respect to continental cratons. Note also parallelism of the opposing Atlantic coastlines. (Bartholomew's Nordic Projection; with permission of John Bartholomew and Sons, Edinburgh.)

Text-Fig. 4:
World Orogenic Belts of the past 700 Million Years (Ediacanan and younger). Early Paleozoic belts also appear on Fig. Wm.9. Note disjunctive belts (those cut off at continental margins) and their apparent matching counterparts on opposite continents in several cases. Note also modern island arcs and oceanic deep trenches. (Bartholomew's Nordic Projection; used with permission)

Text-Fig. 5:
Shields and other major exposures of Precambrian rocks of the world; Precambrian rocks extend beneath all white areas of the continents, but not into the ocean basins. (Bartholomew's Nordic Projection; with permission of John Bartholomew and Son, Edinburgh.)
(After Dott and batten, 1988).

Text-Fig. 6:
Precambrian and Earliest Paleozoic Isotopic-Data Provinces of basement rocks of continents (middle Paleozoic and younger orogenic belts shown blank, emphasizing their general overlapping relationship with older orogenic belt patterns). Note complexity of discordance between provinces. Quality of data varies enormously, being least complete in South America and Asia. (From many sources, e.g., Cahen and Snelling, 1966, the geochronology of equatorial Africa; Compston and Arriens, 1986, Canadian Journal of Earth Sciences; Gastil, 1960, 21st International Geological Congress; Holmes, 1965; Hseih, 1962; Hurley et al., 1967, Science, v. 157, pp. 54-542; Jenks, 1956, International Geology Revie.) (cf. Dott and Batten, 1988).

A. Folded (complex)

B. Volcanic

Text-Fig. 7

Text -Fig. 8

Text-Fig. 9:
Locations of some of the most recently formed volcanoes. (After Tarbuck & Lutgens (1990).

Text-Fig. 10:
Comparison of the three basic types of volcanic structures. **A.** Cinder cone. **B.** Composite cone. **C.** Shield volcano.
(After Tarbuck & Lutgens 1990).

Text-Fig. 11:
Map of the island of Hawaii. **A.** Five volcanoes collectively make up the island. Contour interval is 300 meters (1000 feet). **B.** illustration of the very gentle slope which is characteristic of a shiled volcano (no vertical exaggeration). (After H. T. Stearns and G. A. MacDonald, U.S. Geological Survey).

Text-Fig. 12:
Distribution of the world's major oceanic trenches.

Text-Fig. 13:
Location of several of the larger composite cones that comprise the Cascade Range. (After Tarbuck & Lurgens, 1990)

Text-Fig. 14:
Fast African rift valleys and associated features. After Dott & Batten, 1988).

Text-Fig. 15:
A diagrammatic illustration of a collision between an oceanic plate and a continental one (after the Tasa Collection of Plate Tectonics).

Text -Fig. 16:
A diagrammatic illustration of a collision between two continental plates (after Tasa Collection of plate Tectonics)

Text -Fig. 17:
A diagrammatic illustration for the collision between two oceanic plates (after the Tasa Collection of Plate Tectonics).

Text-Fig. 18:
A diagrammatic illustration for the different types of plate margins (after the Tasa Collection of Plate Tectonic).

Text-Fig. 19:
A diagrammatic illustration for shallow, intermediate and deep-seated earthquakes in an oceanic-continental plate collision (after the Tasa Collection of Plate Tectonic).

Text-Fig. 20:
A diagrammatic illustration for continental rifting which breaks up one continental plate in two by the development of upwarping, followed by the formation of a rift valley, then a linear sea that widens gradually to an ocean (after the Tasa collection of Plate Tectonics).

Text-Fig. 21:
Map of the world showing the distribution of the 12 major lithospheric plates that constitute the outer rocky sphere of the Earth (after the Tasa Collection of Plate Tectonics).

Text-Fig. 22:
Map of the world showing the concentration of the centers of both earthquakes and volcanic activity at the boundaries of lithospheric plates (after the Tasa Collection of Plate Tectonic).

Text-Fig. 23:
A diagrammatic illustration for a cross-section in the Earth showing it various spheres down to the core, and illustrating the two main driving forces for lithospheric plates' movement: convection currents and thermal plumes (after the Tasa Collection of Plate Tectonics).

This book highlights the facts that were not known before the turn of the 20th century, and have just started to be understood within the framework of the recently introduced theory of landforms and plate tectonics. These point only to a single aspect of the miraculous nature of the Qur'an, namely its scientific notions. Among an endless list of evidences that go far beyond the scope of this publication, such explicit, precise and comprehensive scientific statements provide an eloquent testimony to the belief that the Qur'an is the Word of the Creator. Hence, it is the basic source of Divine guidance to man, at a time when all previous revelations have either been lost or distorted.

Born in Egypt, ***Z. R. El-Naggar*** was educated at Cairo University and then got his Ph.D. in 1963 from the University of Wales, U.K. He was awarded the Baraka Geology Prize (Cairo University 1995), the Robertson Post-Doctoral Research Fellowship, (University of Wales, 1963) and the Arab Petroleum Congress' Best Paper Award in 1970. Dr. El-Naggar obtained his full professorship in 1972 and chaired the department in a number of universities. He is a fellow of the Islamic Academy of Sciences in Amman and the Journal of African Earth Sciences in Paris as well as a member or fellow of several other scientific and professional bodies.

Cover design by Xadijah Garrett